Driving Down Emissions

How to clean up road transport?

Richard Howard, Matthew Rooney, Zoe Bengherbi, and David Charlesworth

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Glossary of Terms

Term	Definition
BEV	Battery Electric Vehicle: A vehicle powered by a battery pack and an electric motor alone. It has no engine or fuel tank.
Biofuels	A range of fuels produced from various types of organic matter, including wood, crops, food waste, and algae.
CAV	Connected and Autonomous Vehicle: A vehicle that can operate independently of a driver and that can communicate with its environment and other vehicles.
CNG	Compressed Natural Gas: Natural gas (methane) under high pressure that can be stored in a fuel tank and used to power a vehicle.
DNO	Distribution Network Operator: Regulated companies which own and operate the 14 regional distribution networks across Great Britain
CO_2	Carbon Dioxide (CO_2) is the main greenhouse gas. The vast majority of CO_2 emissions come from the burning of fossil fuels such as coal, gas and oil.
CO_2e	Carbon Dioxide equivalent: A term used to account for the "basket" of greenhouse gasses and their relative effect on climate change compared to carbon dioxide.
Emissions Intensity	A measure of the average greenhouse gas emissions per mile driven in a vehicle, measured in gCO_2/km.
E-REV	Extend-Range Electric Vehicle: A vehicle that is powered by a battery and electric motor, but that also has a small engine to recharge the battery in order to allow longer journeys.
FCEV	Fuel Cell Electric Vehicle: An electric vehicle that is propelled by and electric motor using a hydrogen fuel cell as a source of electricity, rather than a battery.
gCO_2/km	Grams of carbon dioxide equivalent emissions per kilometre. A measure of the "carbon intensity" of a vehicle.
GW	Gigawatt: A measure of power or electrical output. One GW equals 1,000,000 kW.
LPG	Liquefied Petroleum Gas: Propane stored in liquid form that can be used to power an internal combustion engine, instead of petrol or diesel.
Modal shift	Substituting one mode of transport for one that is more efficient, e.g. using public transport or a bicycle instead of a car.
Non-plug-in hybrid electric vehicle	A vehicle that has an internal combustion engine for travelling at moderate to high speed and a small battery capable of propelling the vehicle at slow speeds or of providing extra power to increase the performance of the engine. The battery is charge by the engine.
NO_x	Nitrogen Oxides: A group gaseous pollutants comprised of nitrogen and oxygen that are found in vehicle exhaust fumes as well as other sources. They can be harmful to human health if found in large enough concentrations in the air.
PHEV	Plug-in Hybrid Electric Vehicle: A vehicle with a larger battery than a non-plug-in hybrid that can be charged up using an external source of electric power. Such vehicles also have engines that propel the vehicle when the battery is depleted.
PM	Particulate Matter: Small particles that can come from a range of sources, including transport, and that can be harmful to human health when inhaled.
TWh	Terawatt-hour: A measure of electrical energy equivalent to the power consumption of one terawatt for one hour. One TWh equals 1,000,000,000 kWh.

Executive Summary

Context

Road transport plays a crucial role in society. It enables people and goods to move around the country, thereby sustaining economic growth and prosperity. The 38 million registered vehicles in the UK travelled 324 billion miles on our roads in 2016 - numbers that have increased substantially in recent decades and will continue to grow in the future. I**n order for this to be *environmentally* as well as economically sustainable, it is essential that we tackle the twin problems of greenhouse gas emissions and air pollution from road transport.**

Road transport is responsible for nearly one quarter of total UK greenhouse gas emissions. Unlike other parts of the economy, where significant progress has been made to reduce greenhouse gas emissions, road transport emissions have actually *increased* by 1% since 1990. Improvements in fuel efficiency mean that CO_2 emissions per mile are reducing over time, but this has been offset by an increase in vehicle mileage - with particularly strong growth in the distance travelled by light goods vehicles (e.g. due to the growth in home deliveries). **It is essential that progress is made to reduce greenhouse gas emissions from road transport if the UK is to meet its commitments under the Climate Change Act 2008.**

Transport is also a major source of local air pollution, which is harmful to human health. Our previous report, *Up in the Air*, found that nitrogen oxides (NO_x) and particulate matter (PM) pollution reduces life expectancy by around two years on average across the population of London.[1] This is primarily a diesel problem: road transport is responsible for 80% of the NOx concentrations at roadside locations, and the vast majority of this relates to diesel vehicles. Since the 1990s, successive governments have used a range of fiscal incentives to encourage the use of diesel vehicles on the basis of their superior fuel efficiency and lower greenhouse gas emissions. However, this approach has backfired from a local pollution point of view. Diesel vehicles have far greater NO_x emissions than equivalent petrol vehicles – for example, an average Euro 5 standard diesel car (sold in the period 2010-14) emits almost 20 times as much NO_x per mile as a Euro 5 petrol car. The European Commission has set ever tighter standards for NO_x emissions, but diesel vehicles have systematically failed to meet these standards on the road, culminating in the 'diesel-gate' saga in 2015 concerning the illegal cheating of emissions tests by Volkswagen. **Going forward, the decarbonisation of transport must go hand in hand with reducing air pollution. The Government must not repeat the mistakes of the past, pursuing CO_2 objectives at the expense of air quality.**

Options to clean up road transport

There are a wide range of technology options available to clean up road transport. This report includes a review of the main options, as summarised in the table below. Each has been evaluated in terms of how quickly they could

1 Howard, R. (2016) *Up in the Air: How to solve London's air quality crisis - Part 2*, Policy Exchange

be deployed, their effectiveness in terms of reducing carbon emissions and air pollution, the additional costs to consumers, and the infrastructure requirements for mass uptake.

Table ES1: High level assessment of technology options for cleaning up road transport

	Time to deployment	Decarbonisation potential	Air quality potential	Consumer cost	Infrastructure requirements
Conventional vehicles (inc. non plug in hybrids)	Fast	Medium	Medium	Low	Low
Battery electric vehicles & plug in hybrids	Medium	High	High	Medium	High
Hydrogen fuel cell electric vehicles	Slow	High	High	High	High
Biofuels	Medium	Low	Low	Low	Low
Gaseous fuels	Fast	Low	High	Low	Low
Modal shift	Varies	Medium	High	Low	Varies
Mobility as a service (e.g. car sharing)	Fast	Medium	Medium	Low	Low
Autonomous vehicles	Slow	Uncertain	Uncertain	High	High

The vast majority of vehicles on the road in the UK are **conventional vehicles** with an internal combustion engine (ICE) fuelled by petrol or diesel. Significant improvements in fuel efficiency and carbon emissions have already been made due to vehicle emission targets and financial incentives geared towards lower-CO_2 vehicles. Looking forward, the Committee on Climate Change estimates that new conventional cars sold in 2030 will have real-world CO_2 emissions 37% below those sold in 2010. In recent years, NO_x emissions from diesel vehicles have been well above the required Euro standards, but there are signs that most auto manufacturers are now making improvements.

At present there are relatively few **battery electric vehicles (BEVs)** or **plug in hybrid electric vehicles (PHEVs)** on the road in the UK – around 96,000 as at the end of 2016. Battery technology has improved greatly in recent years, with a reduction in cost and increase in vehicle range. Costs are expected to decline to the point that electric cars and light vans will become cost competitive with conventional vehicles by the early 2020s (without direct subsidy). The major issue with battery electric vehicles is the associated infrastructure for charging. BEV owners typically plug their vehicle in to charge when they return home in the evening. If left unmanaged, this would mean that charging coincides with the daily peak in power demand, which would place additional strain on the power system, requiring investment in local power distribution networks and new generation capacity. However, these issues can be managed if charging is smart and controllable. Vehicles could even feed power back in to the grid in order to help balance the system at times of high demand (although further research is needed into the impact of this on battery life).

Fuel cell electric vehicles (FCEVs) use electric motors for propulsion (like a BEV) but generate the electricity using hydrogen. At present FCEVs are considerably more expensive than conventional vehicles or BEVs, but the cost differential is expected to decrease substantially by 2030. The main advantage of hydrogen over electricity is its higher energy density, which means that FCEVs can travel farther on a single tank of hydrogen than a BEV can on a single charge. Fuel cell technology could potentially be applied to heavy duty vehicles (HGVs and buses) where it will be difficult to apply battery technology due to the weight of the batteries required. One company is developing a hydrogen-powered HGV with a range of 1,200 miles - far beyond the capability of a battery powered HGV. The major drawback lies in the difficulty of producing and transporting low carbon hydrogen. Hydrogen is currently produced primarily from steam reforming of natural gas, which releases significant amounts CO_2. In order for hydrogen vehicles to be 'low carbon', this CO_2 would need to be captured and stored permanently. Alternatively hydrogen could be produced through electrolysis (using a low carbon form of electricity) but at present this process is not cost-competitive.

Biofuels are already in use in the UK, albeit that they make up a relatively low proportion of total transport fuel (around 3%). Biofuels can be blended into conventional fuels or used on a standalone basis given the right engine-fuel combination. Biofuel uptake has been driven by the European Renewable Energy Directive, which mandates that 10% of total transport fuels should be renewable by 2020. The major issues with biofuels are finding enough sustainably-sourced material to create the fuel without displacing farmland for food crops or resulting in land use changes which undermine effective carbon savings.

Fuels derived from **natural gas**, such as **liquefied petroleum gas (LPG)** and **compressed natural gas (CNG)** could offer a fast and relatively low cost strategy to reduce NO_x emissions, although the greenhouse gas emission savings from switching to these fuels is negligible. There are already around 200,000 LPG fuelled cars on British roads, with a network of 1,400 filling stations. CNG buses, meanwhile, are already commonplace in America and could be deployed in UK cities as a strategy to reduce urban air pollution.

Carbon emissions and air pollution can also be reduced through **'modal shift'** - switching from road vehicles to alternative forms of transport. For example, there is potential to shift freight from road to rail, and shift car users to public transport, or cycling/walking for short journeys. These options not only make the transport system cleaner, but also more efficient.

Finally, a range of new technologies may change the way we use road transport. In the short to medium term, we will see further steps towards the provision of **'mobility as a service'** – with a range of companies offering e-hailing of taxis, ride sharing, and car sharing / car clubs. There are already 193,500 car club members in London alone. It is estimated that car club membership reduces a Londoner's transport carbon footprint by 73%, in part due to the fact that car club vehicles tend to be much cleaner than the average car on the road.

In the medium to long term, we will also see a move towards fully **connected and autonomous vehicles (CAVs)**. Many new vehicles already have a degree of connectivity (e.g. navigation) or basic autonomous features (e.g. cruise control).

Car makers and technology firms are now testing fully autonomous cars, but still need to overcome a number of technical and regulatory hurdles before they become commonplace on our roads. Autonomous vehicles have the potential to completely change the way in which we move goods and people around the country – extending the 'mobility as a service' concept described above. Autonomous technology could make vehicles more efficient – through less aggressive driving behaviour and reducing aerodynamic drag by 'platooning'. However, there is a risk of a 'rebound effect' in which autonomous vehicles become so convenient that people use them instead of public transport, thus increasing road miles, congestion, and possibly emissions.

A new strategy to clean up road transport

The Government clearly recognises the need to clean up road transport. However, to date the approach to tackling road transport emissions has been disjointed and insufficient. Despite efforts by successive governments, greenhouse gas emissions from road transport have increased by 1% since 1990. The latest data shows that London plus 74 other cities and local authorities across the UK still exceed the legal and healthy limit for NO_2 concentrations. Far more needs to be done if the new Government is to deliver on its **Manifesto pledges to uphold the Climate Change Act and to 'be the first generation to leave the environment in a better state than we inherited it.'**

As it stands, there is no overarching Government strategy to deliver the required reductions in greenhouse gas emissions, and the latest plan to reduce NO_x emissions is inadequate. The closest thing the Government has to a strategy is the Committee on Climate Change's (CCC) Fifth Carbon Budget[2] - but this is more of a blueprint than a strategy, and the CCC is an advisory body. The CCC's analysis shows that greenhouse gas emissions from road transport could be reduced by 38% between 2010 and 2030, principally through further improvements in the efficiency of conventional vehicles, together with the adoption of ultra-low emission vehicles (ULEVs). However, the same document shows that this level of emissions reduction simply will not be delivered by current and planned policies. **Overall, it is clear that Government needs to develop a new strategy to clean up road transport in order to deliver the emissions reductions required under the fifth carbon budget, and to successfully address air pollution.** This could be developed as a standalone strategy, or as part of the Emissions Reduction Plan (or 'Clean Growth Plan') which the Government is due to release later this year.

Based on our analysis we suggest that the Government's approach should follow the following broad principles:

- **Make a clear commitment to clean up road transport:** The new strategy needs to set out a credible plan of actions to deliver the carbon targets set out in the Fifth Carbon Budget. At the same time, there needs to be closer integration between policies to reduce greenhouse gas emissions and policies to clean up air pollution. The policy to promote diesel vehicles from the 1990s onwards on the basis of lower CO_2 emissions has undermined efforts to improve air quality. The Government needs to learn from this mistake and ensure that policies concerning greenhouse gas emissions are more closely aligned.

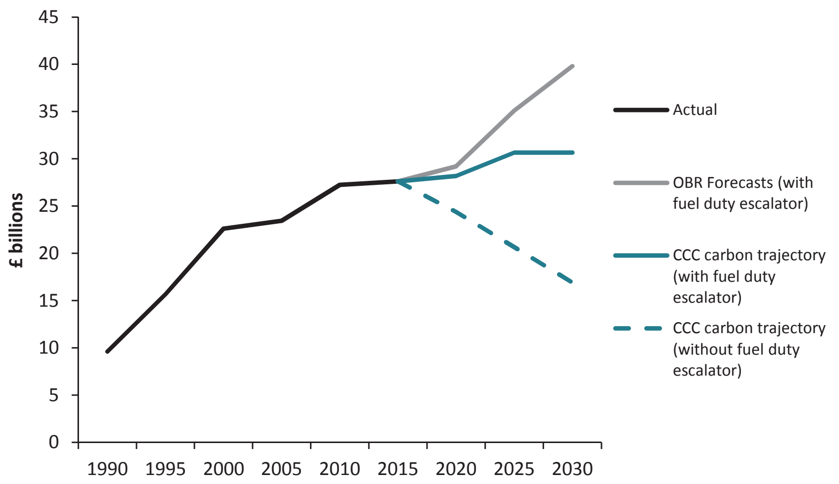
2 Committee on Climate Change (2015) *The Fifth Carbon Budget: The next step towards a low-carbon economy*

- **Provide leadership across Government:** Many different parts of Government have an interest in road transport – including No. 10, HM Treasury, DfT, BEIS, DCLG, Defra, OLEV, the Committee on Climate Change and National Infrastructure Commission, as well as the Devolved Administrations and local authorities. This complexity has led to an uncoordinated approach to reducing road transport emissions. A striking discovery in our analysis was that the Department for Transport and the Committee on Climate Change are working off completely different projections for the total greenhouse gas emissions from road use (with the DfT assuming much higher emissions). Greater coordination is needed to ensure that all parts of Government are working towards a common vision of the future of road transport. **We recommend that the Government establishes a cabinet-level committee focused on emissions reduction and clean growth – potentially as a sub-committee to the Economy and Industrial Strategy Committee.** There is also a need for greater focus and leadership on these issues at a local regional and city scale. **The new Metro Mayors should be a focal point for action to clean up road transport in major UK cities, drawing on experience from London to date.**
- **Put the consumer first:** Voters identify the cost of living as their number one policy issue, and energy costs as their number one concern in terms of household budgets. The Government needs to ensure that consumers remain at the heart of the new strategy to clean up road transport and avoid unduly penalising motorists. It would be morally unacceptable for the Government to heavily penalise diesel drivers who were actively encouraged to switch to diesel by successive Governments. Government should adopt a 'carrot and stick' approach, with a mix of penalties for the most polluting vehicles and incentives for cleaner vehicles. **To this end, we reiterate our call for a diesel scrappage scheme to take more polluting vehicles off the road, alongside measures such as Clean Air Zones which will restrict the most polluting vehicles from entering cities.**
- **Pursue a technology-neutral, least-cost approach:** We strongly believe that the most cost-effective way to clean up road transport will be to adopt a technology neutral approach. This means exploring all opportunities to reduce emissions on a fair and equal basis, and setting policies to achieve specific environmental outcomes rather than targets for any individual technology. **To this end, the Government should scrap the European target for 10% renewable transport fuels by 2020 and avoid setting targets for the number of ultra-low emission vehicles on the road.** The uptake of ultra-low emissions vehicles should be decided by market forces rather than government decree.
- **Tackle Infrastructure System Challenges:** Cleaning up road transport could have significant implications for infrastructure – including transport, energy and even communications systems. Whilst we can already identify and describe these system implications at high level, there is still significant uncertainty as to the precise nature, scale and timing of the impacts and infrastructure requirements. This raises questions in terms of how to plan network and system investments given the high level of uncertainty. **For this reason, we suggest that Ofgem should seriously consider shortening the length of the next set of price controls for energy networks (e.g. from 8 to 5 years) or building in more significant re-openers, to cater for uncertainties.**

Finally, the Government needs to recognise the significant fiscal implications of cleaning up road transport. Road use currently generates £34 billion in tax receipts through fuel duty and road tax alone.[3] Total fuel duty receipts increased rapidly to 2010, but have since stalled due to the decision to repeatedly cancel the fuel duty escalator. Actual fuel duty receipts in 2015/16 were £7 billion lower than the Office for Budgetary Responsibility (OBR) was projecting for the same year in 2010.

Fuel duty is effectively a tax on carbon emissions, whilst road tax is in part designed around CO_2 emission bands. This means that, all else being equal, tax receipts from road use will decline as road transport is decarbonised. The OBR's 2014 Fiscal Sustainability Report suggested that fuel duty receipts could reach £40 billion per year by 2030 (based on DfT projections for road use and carbon emissions). However, if instead we achieve the carbon trajectory suggested by the CCC, then total fuel duty receipts would be far lower – reaching £31 billion in 2030 with the fuel duty escalator, or £17 billion without.[4] **In other words, assuming we achieve the fifth carbon budget emissions trajectory, fuel duty receipts could be £9-23 billion lower in 2030 than the OBR is currently assuming.** On a cumulative basis, this represents a loss of £60-170 billion in tax receipts between now and 2030.

Figure ES2: Scenarios for fuel duty receipts



HM Treasury is already alive to this possibility, and has already made changes to road tax and Company Car Tax rates to reflect the trend towards lower CO_2 vehicles.

However, there are still some significant flaws in the system that gave rise to serious side effects. For example, the current system of fiscal incentives relies on official emissions estimates that are known to be inaccurate. Moreover, official emission estimates only include direct tailpipe emissions, and completely ignore indirect emissions associated with the generation of power used to charge the battery. For Plug-in Hybrid Electric Vehicles in particular, this means that official figures advertised by manufacturers give a highly misleading picture as to the true miles per gallon or CO_2 emissions per km on the road – yet PHEVs are still eligible for grants and reductions in road tax and company car tax. **Government**

3 Office for Budget Responsibility (2017) *Economic and fiscal outlook*

4 Note that our model assesses first order effects of changing parameters such as the fuel duty rate or total carbon emissions. It does not consider second order effects such as fuel switching.

should develop a new system for rating vehicle emissions, that takes into account both direct and indirect emissions, and underpins tax incentives going forward.

Our analysis suggests that the total tax take from road use could be equal to or less than the cost of maintaining the road network by the 2030s (in a scenario consistent with the Fifth Carbon Budget). **On this basis, the Government needs to seriously consider whether in the long term it will be necessary to move from the current system of taxing fossil fuels and carbon emissions to a system of road user charging (e.g. toll roads, charges per mile, or congestion charges in cities).**

Technology specific recommendations

The report makes a number of detailed policy recommendations concerning individual technologies:

Conventional vehicles

- **Clarify the UK's position regarding European vehicle standards and emissions targets following Brexit.**
- **Improve transparency on real-world NO_x emissions,** by requiring all manufacturers and vehicle retailers to display this information at the point of sale.
- **Introduce Clean Air Zones in the most polluted cities,** where NO_2 levels are likely to exceed legal limits in the 2020s without further action. Vehicle charging should only be introduced where it is strictly necessary.
- **Ensure that all charging schemes and Clean Air Zones correctly target the most polluting vehicles.** As currently defined, the London 'Toxicity Charge' fundamentally fails to meet this requirement.
- **Introduce a targeted Vehicle Scrappage/Retrofit Scheme,** alongside the introduction of Clean Air Zones, to take the most polluting vehicles off the road.

Ultra -low emission vehicles

- **Continually review the system of grants for ULEVs to ensure that they represent value for money.** The Government should signal a phase out of grants for BEVs and PHEVs (cars and light vans) by the early 2020s, by which time cost reductions will mean they will be cost-competitive with conventional vehicles without grants.
- **Government should continue to provide grants for FCEVs,** but cap the total grant funding available.
- **Continually review the system of grants for home, workplace, and on-street charging points** to ensure that Government is not over-subsidising their deployment. The Government should signal a phase out of subsidies for charging points by around 2020.
- **Put in place an appropriate regulatory framework to create a competitive market for battery electric vehicle charging and hydrogen refuelling.** Electric charging infrastructure and services are currently unregulated, creating

significant risk for investors and consumers, and should be brought within the remit of Ofgem (the energy regulator).

- **Conduct further research into the public perceptions of smart charging** to determine how consumers are likely to respond to time of use tariffs.
- **Ensure that all electric charging infrastructure is smart and controllable** in order to minimize the investment required into local power networks and additional electricity generation capacity.
- **Ensure that data is collected on the location and usage of all electric charging points in the UK** (public and private) and this data made available in an appropriate form to energy suppliers, network operators and Government.
- **Commission further research into how to reduce the cost of low carbon hydrogen production,** transport, storage, and refuelling infrastructure.
- **Focus hydrogen vehicle research initially on HGVs and buses** as these appear to be the vehicle segments where hydrogen has an advantage over BEVs.

Biofuels

- **Abandon the arbitrary European target of 10% renewable transport fuel by 2020** (which it is unlikely to be achieved in any case) and re-examine policies concerning biofuels.
- **Continue to focus on biofuels derived from wastes rather than energy crops.**

Natural gas (LPG and CNG)

- **Consider replacing older buses with new models running on natural gas,** as a short term measure to reduce NO_x emissions.
- **Expand incentives offered to taxi operators under the Clean Vehicle Technology Fund to convert diesel taxis to run on LPG.**
- **Provide greater certainty for motorists about fuel duty on LPG and other gaseous fuels,** maintaining the current differential between fuel duty on LPG versus petrol/diesel for a period of 5-10 years.

Modal shift and behaviour change

- **Work with the rail industry to increase the amount of freight shipped by rail,** by identifying spare capacity on the network and how it can be used, and resolving pinch points on the network.
- **Accelerate the electrification of the rail network, such that by 2030 the 'core network' can be operated by electric trains,** and make targeted investments to increase the use of electric locomotives for freight. Where electrification is unviable, Government and the rail industry should investigate the feasibility of electric/diesel hybrids and battery powered trains.
- **Explore the potential to convert existing train lines to light rail, train-tram and ultra-light rail,** which could then be factored into future rail franchises.
- **Allow all local authorities (not just those with an elected Mayor) to take a leading role in the tendering of bus services.**
- **Increase the proportion of the overall transport budget spent on cycling and walking, and adopt the 'London Cycling Design Standards' as a national standard.**

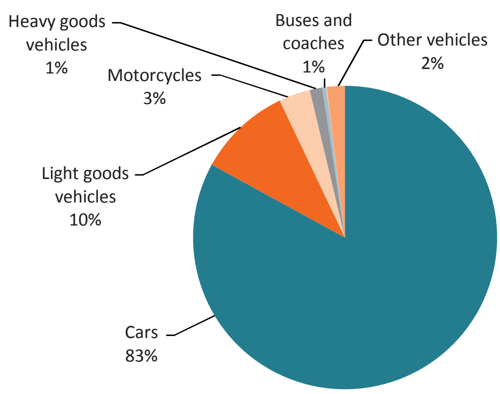
- **Integrate 'mobility as a service' solutions such as car sharing into transport information systems (such as 'CityMapper') and smart charging systems (such as Oyster).**
- **Metro Mayors and Local Transport Authorities should coordinate 'mobility as a service' solutions across city-regions.**
- **Provide clear leadership on the development of connected and autonomous vehicles,** with a more coherent joined-up strategy. Government should conduct further research into the consumer acceptance of connected and autonomous vehicles, and the likely benefits in terms of emission savings.
- **Carry out further research to better understand the communication network requirements associated with connected autonomous vehicles,** in order to future-proof investment in communications and transport systems.
- **Develop a set of standards and regulations concerning the safety, security and data privacy aspects of connected and autonomous vehicles,** drawing on best practice from around the world.

1
Introduction

Road transport in the UK

Transport plays a crucial role in society, enabling people and goods to move around the country, thereby sustaining economic growth and productivity.[5] Our pattern of transport use in the UK is predominantly road based, and within that a significant proportion of journeys are made by car. Road vehicles travelled a total of 320 billion miles on UK roads in 2016.[6] Around 80% of total road traffic relates to cars and taxis, and this proportion has been almost unchanged since the 1970s. Similarly, of the 38.5 million licensed vehicles on the road in the UK,[7] just over 80% are passenger cars (Figure 1.1).

Figure 1.1: Vehicles on the road in the UK[8]



There has been a sustained increase in road use in recent decades, with total vehicle mileage increasing tenfold since 1950. Overall traffic growth slowed in the period 1990 to 2010, due to the two recessions and an increase in the cost of motoring, but traffic growth has resumed since 2013 and has now overtaken the previous peak in 2007. Projections by the Department for Transport suggest that total vehicle miles in England could increase by a further 23% between 2015 and 2030, leading to a 5% reduction in average speeds, and a 31% increase in congestion delays.[9]

5 Edington, R. (2006) *Transport's role in sustaining the UK's productivity and competitiveness*

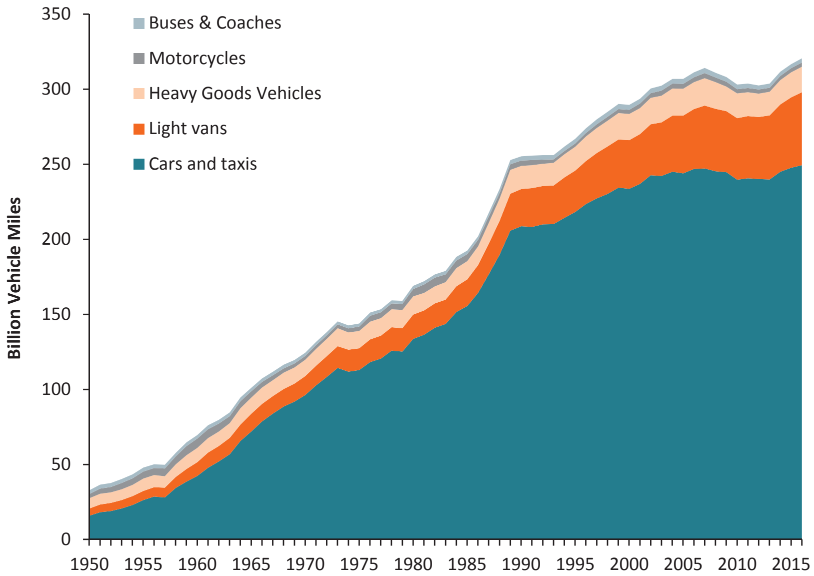
6 DfT statistics

7 DfT (2016) *Vehicle Licensing Statistics*, 8 September 2016

8 Ibid.

9 DfT (2015) *National Traffic Congestion and Emissions projections 2015*

Figure 1.2: Total distance travelled by type of vehicle



The average person in England currently travels 6,600 miles per year (across all forms of transport) making a total of over 900 journeys, which are 7.3 miles each on average.[10] Passenger travel is predominantly car based: trips by car account for 78% of the total distance travelled. In fact, cars are the predominant form of passenger transport for trips of all lengths except those under 1 mile, where walking and cycling dominate.

Around three-quarters of all households in England now own at least one car. Wealthier households are more likely to own one or more cars, and travel further on average each year. Journey time statistics show that 80% of the working age population can reach seven or more employment centres by car, compared to only 20% by public transport. As discussed in our report, *On the Move*[11], the car is the 'ultimate enabler of mobility' and 'people who own a car are more likely to be in employment.'

The amount of car traffic has expanded significantly, from less than 100 billion vehicle miles in 1970 to 210 billion vehicle miles in 1990. That said, growth in car traffic slowed from 1990 onwards, increasing by 12% during the 1990s, and just 3% in the 2000s (compared to 56% growth in the 1980s).

Whilst the growth in car and passenger traffic has slowed, road freight continues to see significant growth – particularly in the form of light vans (as opposed to Heavy Goods vehicles). Total van traffic increased by 89% over the period 1990 to 2015 (compared to 24% growth across all vehicle types) and the number of licensed vans increased from 2.4 million vans in 2000 to 3.8 million vans in 2016. This is a result of the sustained and rapid growth in online retail and home deliveries that has taken place since the early 2000s. The growth in HGV traffic has been far slower (8% increase since 1990). The total number of licenced HGVs in Britain increased from 420,000 in 1994 to 483,000 in 2015.

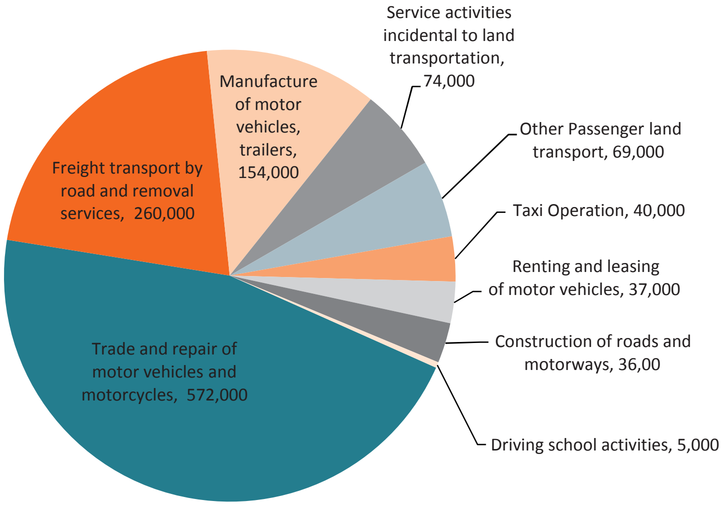
As well as being the predominant form of transport in the UK, road transport and associated industries also represent a significant component of the UK

10 DfT Statistics Table NTS0101

11 Hind, D. (2015) *On the Move: How to create a more mobile workforce*, Policy Exchange

economy. Road transport related industries comprise 140,000 firms employing 1.25 million people (or 4% of total UK employment), with a combined turnover of over £300 billion per year and Gross Value Added of £88 billion. The bulk of this relates to the trading and repair of motor vehicles (570,000 employees) whilst freight transport employs 260,000 people, and the manufacture of motor vehicles (including parts, components and accessories) employs a further 150,000 people.

Figure1.3: Employment associated with road transport[12]



Cleaning up road transport

In order for road transport to be environmentally as well as economically sustainable, it is essential that we tackle the twin problems of greenhouse gas emissions and air pollution from road vehicles.

Greenhouse gas emissions

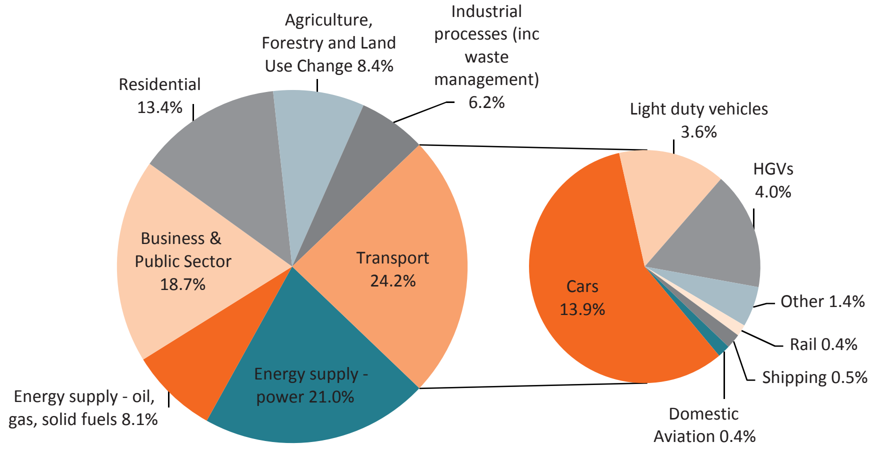
The UK has set an ambitious set of targets to reduce greenhouse gas emissions in order to mitigate the effects of climate change. Under the Climate Change Act (2008),) the UK has committed to reducing total greenhouse gas emissions by 80% by 2050 (compared to 1990 levels) as well as setting a number of five-yearly 'carbon budgets', the latest of which covers the period 2028 to 2032. As part of the Paris Agreement on climate change in 2015, the UK also agreed to a longer term target to achieve 'net zero' global greenhouse gas emissions during the second half of the twenty-first century in order to limit warming to 2oc, and pursue efforts to limit warming to 1.5oc.[13]

Transport is the single largest source of greenhouse gas emissions in the UK, making up 24% of total emissions in 2015 (Figure 1.4). Within this, private cars represent the largest source of emissions (14% of total UK greenhouse gas emissions), followed by vans and HGVs (4% each). Non-road transport emissions are relatively insignificant by comparison, making up 1.7% of UK greenhouse gas emissions in total (comprising domestic aviation, shipping, rail, and military vehicles).

12 Source: ONS, Annual Business Survey. Datapoints relate to 2015, or 2014 where 2015 is unavailable.

13 Committee on Climate Change (2015) *UK climate action following the Paris agreement*

Figure 1.4: Total greenhouse gas emissions by sector[14]



Little if any progress has been made to reduce transport-related greenhouse gas emissions over the last few decades, despite progress in reducing emissions from other sources (Figure 1.5). Greenhouse gas emissions from all types of domestic transport have fallen by just 2% since 1990, whilst emissions from road transport have actually *increased* by 1% over the same period. Total road transport emissions peaked in 2007, then fell by 11% in the period 2008-13 following the Great Recession, but have since increased by 3% to just above the emissions levels seen in 1990.

By comparison, greenhouse gas emissions associated with the generation of electricity have halved since 1990, and this fall has accelerated since 2012 with the closure of a significant number of coal power stations (as discussed in our recent report, *Power 2.0*[15]). Significant reductions in greenhouse gas emissions have also been achieved in other sectors such as waste management (as highlighted in our recent report, *Going Round in Circles*[16]).

The lack of progress in reducing transport emissions means that they are increasing as a share of total UK emissions (domestic transport increased from 15% of total UK greenhouse gas emissions in 1990, to 24% in 2015). The Committee on Climate Change has already flagged the lack of progress on transport emissions as a concern. Their analysis shows that based on current policies, the UK is on track to deliver the second and third carbon budgets (which cover the period 2012-22) but exceed the fourth and fifth carbon budgets by a wide margin (which cover the period 2022-32).[17] **This suggests that in order to meet overarching carbon targets, Government will need to focus more on decarbonising road transport, where no progress has been made to date.**

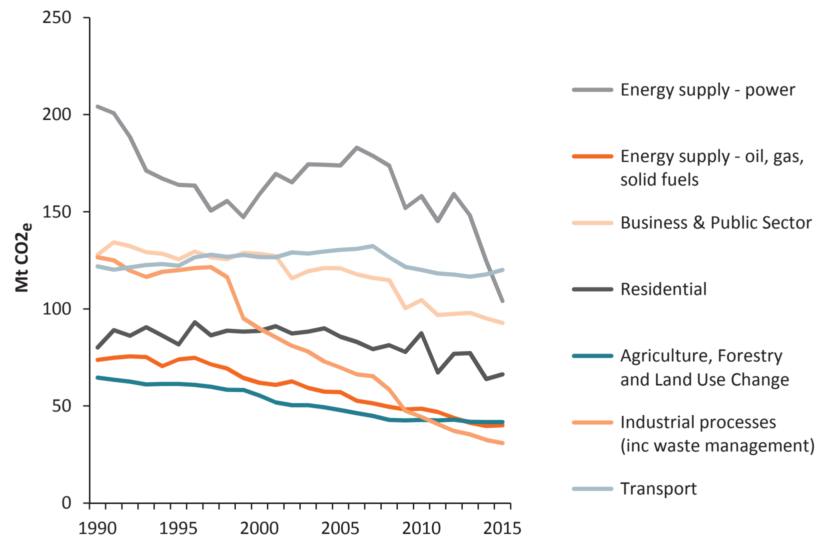
14 BEIS (2017) *Final greenhouse gas emissions national statistics for 2015*. 'Other' includes buses, motorcycles, liquefied petroleum gas fuelled vehicles, and military vehicles.

15 Howard, R. and Bengherbi, Z. (2016) *Power 2.0*, Policy Exchange

16 Howard, R. & Galloway, T. (2017) *Going Round in Circles*, Policy Exchange

17 Committee on Climate Change (2016) *Meeting Carbon Budgets – 2016 Report to Parliament*

Figure 1.5: Greenhouse gas emissions by sector, 1990-2015[18]



The overall trend in road transport-related greenhouse gas emissions masks some significant changes which have occurred at a more granular level:

Efficiency gains: Vehicles are becoming far more efficient over time, increasing the miles per gallon and reducing the 'CO_2 intensity' of the fleet (or emissions per mile travelled). Significant improvements in fuel efficiency have been achieved since the first European exhaust emissions standards for passenger cars were introduced in 1970. The European Commission brought in a mandatory system for the labelling of new passenger cars in terms of fuel economy and CO_2 emissions (Directive 1999/94/EC). By introducing clearer labelling on fuel economy and emissions, consumers were able to make more informed choices. Added to this, the Government has encouraged the purchase of vehicles with lower CO_2 emissions through fiscal incentives such as road tax, company car tax, and enhanced capital allowances (as discussed in our report, *Up in the Air*[19]). The European Commission also set a target for all car manufacturers to achieve average emissions of 130g CO_2 per km across all new car sales by 2015. A more stringent target of 95g/km will apply from 2021.

As a result of these regulations, new cars now emit around one third less CO_2 than two decades ago (123g CO_2/km compared to 186g CO_2/km in 1995)[20] and the emissions intensity of the overall car fleet is now 20% lower than in 1990 (Table 1.1). More generally, there has been a 19% reduction in CO_2 intensity across all vehicle types.[21] Within this, the largest reduction in CO_2 intensity has been for buses and coaches (-27%), followed by vans (-18%), motorcycles (-16%), and then HGVs (-11%).

Increase in vehicle mileage: Whilst efficiency improvements have been made, these gains have been entirely offset by people driving more than they did previously (in part due to an expansion of the road network). The total distance travelled by all forms of road transport increased by 24% since 1990, which offset and slightly exceeded the improvement in CO_2 intensity of the fleet, resulting in

18 Committee on Climate Change (2015) *Fifth Carbon Budget*

19 Howard, R. (2016) *Up in the Air: How to solve London's air quality crisis – Part 2*, Policy Exchange

20 ACEA (2016) *Reducing CO_2 Emissions from Passenger Cars and Light Commercial Vehicles Post-2020*, European Automobile Manufacturers Association

21 Weighted by the total distance travelled per vehicle type

a 1% increase in road transport related greenhouse gas emissions. The distance travelled by vans (+89%) vastly exceeded the improvement in CO_2 intensity of the van fleet (-18%), resulting in a 55% increase in total greenhouse gas emissions from vans. For cars and HGVs, the increase in distance travelled was outweighed by the improvement in CO_2 intensity. In the case of motorcycles, buses and coaches, the reduction in greenhouse gas emissions is a product of a reduction in both distance travelled and CO_2 intensity.

Table 1.1: Changes in total emissions, CO_2 intensity and distance travelled over period 1990-2015[22]

	Change over period 1990-2015		
	Distance travelled	CO_2 intensity of the fleet	Total greenhouse gas emissions
Vans	+89%	-18%	+55%
Cars	+19%	-20%	-4%
HGVs	+8%	-11%	-4%
Buses and Coaches	-4%	-27%	-30%
Motorcycles	-20%	-16%	-33%
All Road Transport	+24%	-19%	+1%

Increasing gap between official and real-world emissions: Another trend to emerge in recent years is the widening gap between official fuel efficiency and CO_2 figures, and the actual performance of vehicles on the road. As noted above, European regulations require auto manufacturers to publish official estimates of fuel economy and CO_2 emissions. These figures are arrived at through standardised tests in laboratory conditions, which allow different vehicle models to be compared against each other on a consistent basis. However, numerous recent investigations have revealed that vehicle performance in real-world conditions tends to be significantly worse than official figures would suggest.[23] As highlighted in our report, *Up in the Air*, the tests 'do not adequately represent real world driving conditions – particularly urban driving conditions … vehicle manufacturers have employed a range of increasingly sophisticated strategies simply to pass the test itself, leading to an increasing gap between test figures and actual world performance.'[24] Discrepancies occur due to a number of factors such as driving styles, use of customer comfort systems (i.e. air-conditioning), vehicle loading, and traffic conditions, which cannot all be taken into account in standardised laboratory tests. Powerful lobby groups, such as auto manufacturers in industry groups, have argued against measures to tighten the vehicle testing regime.

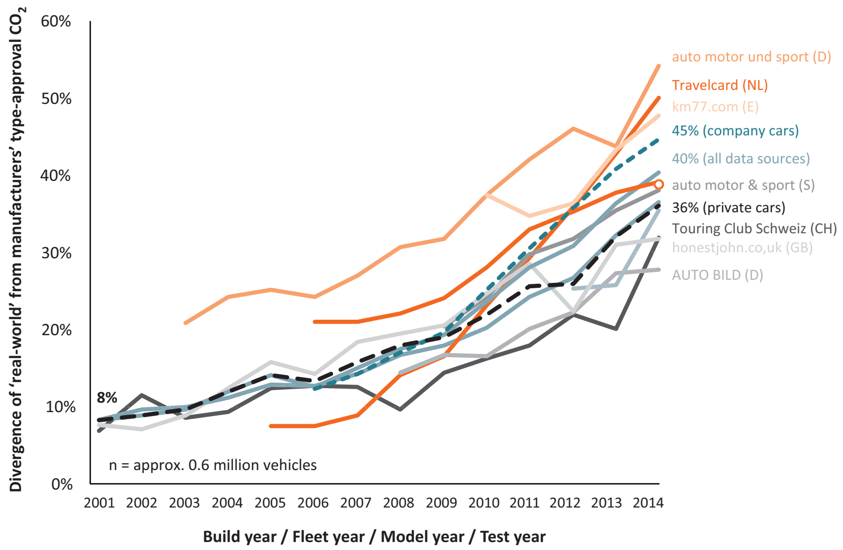
Figure 1.6 summarises the results from a number of different studies that estimated the difference between real-world performance and official figures for CO_2 emissions. It shows that as stricter emission regulations have been introduced, the divergence between test results and real-world performance has increased substantially. **On average, the studies found that real-world CO_2 emissions are now 40% higher than official figures from laboratory tests.**

22 BEIS (2016) 'Final UK greenhouse gas emissions national statistics 1990-2015'; DfT statistics; Author's calculations

23 International Council on Clean Transportation (2015) *From Laboratory to Road: A 2015 update of official and "real-world" fuel consumption and CO 2 values for passenger cars in Europe*

24 Howard. R (2015) *Up in the Air: How to Solve London's Air Quality Crisis - Part 1*, Policy Exchange

Figure 1.6: Divergence between real-world and manufacturers' type-approval CO_2 emissions[25]



In response to this, the EU announced it will move to a new testing regime called the 'Worldwide harmonized Light vehicles Test Procedure' (or WLTP) from 2017 onwards. The new testing regime will incorporate a number of different test cycles designed to represent real world driving conditions in different settings (i.e. urban and motorways). For example, the testing regime reflects data on how drivers tend to accelerate and brake in practice.

Air pollution

Alongside greenhouse gas emissions, another key issue for policy-makers is the air pollution arising from road transport. As discussed in our recent report, *Up in the Air*, the UK has a significant issue concerning ambient air pollution, particularly in urban areas.[26] The problem of air pollution has gained increasing attention in recent years, in part due to the 'diesel-gate' saga concerning Volkswagen's use of illegal 'cheat devices' during vehicle emissions tests, as well as ongoing legal disputes concerning the UK Government's air quality plans.

The EU Air Quality Framework Directive sets Emission Limit Values for a number of pollutants including nitrogen dioxide (NO_2) and particulate matter (PM), based on World Health Organisation guidelines. Exposure to these pollutants is linked to a range of health effects such as asthma, lung cancer, respiratory infections, cardiovascular diseases, and even premature death. **It is estimated that particulate matter pollution had a mortality impact equivalent to nearly 29,000 deaths across the UK in 2010.**[27] The effect of NO_2 on human health is thought to be of similar magnitude but has yet to be quantified officially.[28]

NO_2 pollution is a particularly bad problem for London, with NO_2 levels similar to cities such as Shanghai and Beijing, which are amongst the worst cities globally in terms of overall air quality. Our analysis identified that in 2010, 12.5% of London's area exceeded the legal and healthy limits for nitrogen dioxide. This area included schools attended by 328,000 children (25% of all schoolchildren

25 ICCT (2015) 'Real-world vehicle fuel economy gap continues to widen in Europe', press release

26 Howard, R. (2015) *Up in the Air: How to Solve London's Air Quality Crisis - Part 1*, Policy Exchange

27 The Committee on the Medical Effects of Air Pollutants (2010) The Mortality Effects of Long-Term Exposure to Particulate Air Pollution in the United Kingdom

28 Defra (2016) Valuing impacts on air quality: Updates in valuing changes in emissions of Oxides of Nitrogen (NO_x) and concentrations of Nitrogen Dioxide (NO_2)

in London) plus a workplace population of 3.8 million people (representing 44% of London's workday population). The most polluted roads in London far exceed NO_2 standards – for example, the average NO_2 concentration on Putney High Street in 2016 was over 120 µg/m3 – three times the legal limit.[29] London now complies with European limits for particulate matter, albeit that these standards are far higher (i.e. less stringent) than the guideline levels suggested by the World Health Organisation. **Overall, it is estimated that air pollution reduces life expectancy by around 2 years on average across the population of London.**[30]

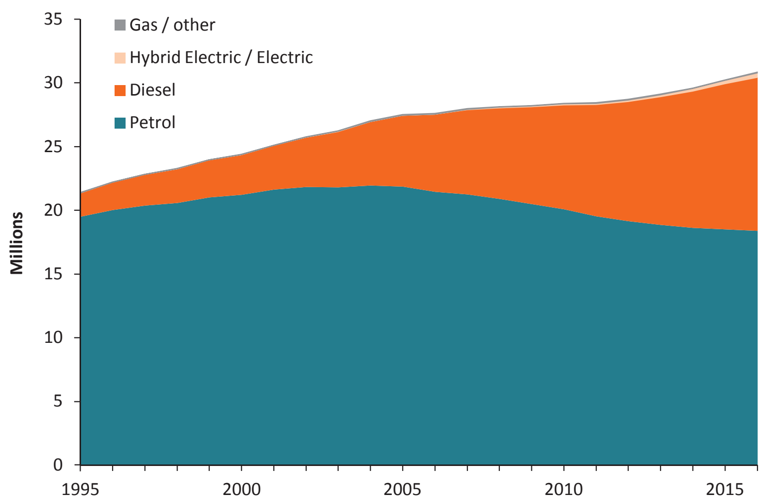
Much progress has already been made to reduce NO_x emissions across the UK – with total emissions falling by 70% since 1970 and 19% since 2010.[31] However, despite this, the latest data from Defra shows that Greater London plus 74 other local authorities still exceed the limit value for NO_2.[32]

The problem of NO_x emissions is mainly a diesel problem. Defra analysis shows that road transport is responsible for 80% of the NO_x concentrations at roadside locations across the UK.[33] The vast majority of road transport emissions relate to diesel rather than petrol vehicles. In Greater London, more than 80% of total NO_x emissions from road transport relates to diesel vehicles, predominantly to diesel cars (25%), Heavy Goods vehicles (25%), buses and coaches (20%), and vans (10%); whilst petrol cars represent 16% of total NO_x emissions.[34]

The failure to control NO_x emissions from road transport is down to two main factors – the growth in the number of diesel vehicles since the 1990s, combined with the failure of vehicle emissions standards to control emissions from diesels:

Dieselisation of the fleet: There has been a rapid and significant shift towards diesel vehicles in the UK over the last two decades, as in many other European countries. In 1994, there were 1.6 million diesel cars on the road in Great Britain, making up 7% of the total fleet. Diesels increased from 18% of all new cars sold in 2001, to 50% of new sales in the period since 2011 (albeit that sales of diesel cars have recently dropped). There are now 11.4 million diesel cars on the road, making up 38% of the total car fleet (as at the end of 2015). A similar trend has also taken place for light goods vehicles, where diesels went from 51% of the total fleet in 1994, to 96% in 2015.

Figure 1.7: Stock of cars in Great Britain by fuel type



29 The Guardian (2017) 'London breaches annual air pollution limit for 2017 in just five days'

30 The *Financial Times* (2017) 'The hidden air pollutants in your home - and how to fight them'

31 Defra, DfT (2017) Improving air quality in the UK: tackling nitrogen dioxide in our towns and cities

32 Ibid.

33 Ibid.

34 Howard, R. (2016) *Up in the Air: How to solve London's air quality crisis – Part 2*, Policy Exchange

Diesel vehicles have been promoted heavily by Government since the1990s on the basis that they achieve greater fuel efficiency and lower greenhouse gas emissions than equivalent petrol vehicles. By virtue of the fuel itself, the engine design and the combustion process, diesel vehicles are around 20% more efficient than those running on petrol. Successive governments have encouraged the use of diesel through a combination of fiscal incentives such as road tax, company car tax, and capital allowances, which are all geared towards lower CO_2 vehicles but fail to recognise air pollution arising from diesels.

Failure to control NO_x emissions: Whilst diesels have been favoured for fuel economy and CO_2 reasons, they emit far greater levels of local pollutants such as NO_x and PM. For example, diesel cars sold in the period 2010 to 2014 emitted 20 times more NO_x than petrol cars on average.[35] In order to address this, the European Commission introduced a system of 'Euro' Standards from 1992 onwards to control emissions of NO_x and other pollutants from cars, vans and HGVs. The latest Euro 6 standards were introduced in 2014 for cars and 2013 for HGVs.

In theory, these standards should have controlled emissions of NO_x and PM from both diesel and petrol vehicles. However, under this system, the emission standards for petrol vehicles are much tighter than for diesels. For example, under the Euro 3 emissions limits introduced in 2000, the NO_x emissions limit for diesel cars (0.5g/km) was more than three times that of petrol cars (0.15g/km), and this disparity was maintained under Euro 4 and Euro 5 (e.g. for cars sold until 2014).

Moreover, manufacturers have systematically failed to achieve the stated NO_x emission limits for diesels in practice, whereas petrol cars have generally conformed to the standards. Similar to the issues with official CO_2 tests, there is a wide disparity between NO_x emissions in laboratory conditions versus performance in real-world conditions. Research by King's College London in 2011, based on remote sensing data from cars on the road in London, found that there had been little or no improvement in NO_x emissions from diesel cars, vans, HGVs or buses over the preceding 20 years, although there had been a significant improvement for petrol cars. The same research showed that Euro 5 diesel cars (sold until 2014) performed no better than pre Euro 1 cars (sold in the 1980s) in terms of NO_x emissions.

More recent testing by the International Council on Clean Transportation (ICCT) found that NO_x emissions from a typical Euro 6 diesel car are 7-10 times the relevant standard.[36] Similarly, testing of a sample of Euro 5 and Euro 6 diesel cars by the Department for Transport found that every single car exceeded the relevant limit for NO_x emissions in practice. The sample of Euro 5 cars had average NO_x emissions of 1135 mg/km – six times the Euro 5 limit (180 mg/km). The sample of Euro 6 diesel cars did have lower emissions on average at 500 mg/km, but this was still six times the Euro 6 NO_x emissions standard (80 mg/km).[37]

Whilst the NO_x performance of diesel cars is highly questionable, there is evidence that the Euro VI standard for Heavy Goods Vehicles has led to an improvement. Analysis by TfL showed Euro VI trucks achieve a 77% reduction in real world NO_x emissions compared to Euro V trucks, whilst Euro VI buses achieved a 98% reduction in NO_x compared to Euro V buses. This is due to a significant improvement in NO_x emissions at lower speeds, which is particularly

35 Ibid.

36 Transport and Environment (2015) *Five facts about diesel the car industry would rather not tell you*

37 DfT (2016) *Vehicle Emissions Testing Programme*

important in the context of urban driving conditions. If the estimated savings from Euro VI are delivered in full, this would mean that new Euro VI buses and HGVs would have lower NO_x emissions than many Euro 5 diesel cars.

In summary, the experience over the last two decades has shown that there is a potential tension between the achievement of air quality and decarbonisation objectives. The promotion of diesel vehicles, combined with the failure of the vehicle testing regime, has undermined efforts to improve air quality. Barry Gardiner MP, the shadow minister for energy and climate change, has acknowledged that the policy to promote diesels under Gordon Brown's government was a mistake, with a lack of evidence at the time on the air quality impact of diesels.[38] **Going forward, Government needs to focus on policies and technologies that deliver a reduction in both greenhouse gas emissions and air pollution.**

38 Gardiner, B. (2017) 'Coming clean on diesel', Politics Home

2

Options to Clean Up Road Transport

This chapter provides a review of the different options that could be pursued to clean up road transport. We consider a number of options, as follows (see Table 2.1):

- **Conventional vehicles –** further improvements in the efficiency of conventional vehicles, including non-plug in hybrids.
- **Ultra-low emission vehicles –** adopting new types of vehicles that have zero or ultra-low emissions at the exhaust, such as battery electric vehicles and hydrogen-powered vehicles.
- **Alternative fuels –** such as biofuels and natural gas fuels.
- **Modal shift –** replacing road transport with another mode of transport, for example shifting freight from road to rail, or shifting passenger trips from cars to public transport or cycling.
- **Behaviour change –** considering a range of technology options that could change driving behaviour and thereby reduce transport emissions, such as car sharing, and autonomous and connected vehicles.

We look at each of these options in turn and consider the following factors:

- **Emissions reduction –** the potential for each of the options to reduce emissions of greenhouse gases and local pollution (principally considering NO_x emissions). Within this, we consider the applicability of the technology to different vehicle types where relevant (car, van, HGV and bus).
- **Consumer cost –** the cost of each option to the end consumer, in terms of both upfront cost and running costs. Where relevant we also consider other factors that may limit consumer support such as consumer perception and quality/performance issues.
- **Infrastructure cost/impact –** the challenges and costs associated with delivering the infrastructure needed to support each option, including charging or refuelling stations, and upstream infrastructure requirements such as distribution networks and generation of alternative fuels.

Table 2.1: Options to decarbonise road transport

Options		Description	Fuel	Drivetrain	High Voltage Battery
Vehicle efficiency	Conventional Internal Combustion Engine (ICE)	Improvements in conventional ICE vehicles to reduce GHG and local emissions. E.g. through design, materials, aerodynamics, emissions abatement, downsizing.	Petrol/Diesel	ICE	No
	Petrol/diesel Hybrid (non-plug-in)	Hybridisation of petrol/diesel ICE, but without the ability to plug in. Petrol/diesel remains the sole fuel. The degree of hybridisation varies between models from mild to full hybrid.	Petrol/Diesel	ICE	Yes
Ultra-Low Emission Vehicles (ULEVs)	Battery Electric Vehicle (BEV)	Vehicle with purely electric propulsion. All electricity is provided by plugging in to the grid.	Electricity	Electric motor	Yes
	Plug in Hybrid (PHEV) inc. Extended Range EV (E-REV)	A full hybrid with plug in functionality. Can run on just the ICE, the electric battery, or a combination of both. The electric battery is charged either by plugging in, or by the ICE.	Mix of petrol/diesel and grid electricity	Electric only (series hybrid) or combination with ICE (parallel hybrid)	Yes
	Fuel Cell Electric Vehicle (FCEV)	Stores energy as hydrogen, which then goes through a fuel cell to power an electric motor.	Hydrogen	Electric motor	Varies
Alternative fuels	Biofuels	ICE using biofuels (either wholly or mixed with petrol/diesel).	Biofuels	ICE	No
	Gaseous fuels	ICE powered by LPG / CNG / LNG	LPG/ CNG/ LNG	ICE	No
Modal shift & behaviour change	Freight	Shifting freight from road to alternatives such as rail	Various	Various	Various
	Passenger cars	Shifting passenger car trips to alternatives such as public transport or cycling.	Various	Various	Various
	Mobility as a service	E-haling, ride-sharing, and car sharing technologies	Various	Various	Various
	Autonomous vehicles	Addition of autonomous / driverless features to any of the vehicle types listed above.	Various	Various	Various

Conventional vehicles

Emissions reduction

As it stands, the UK's vehicle fleet is composed almost entirely of conventional petrol and diesel vehicles powered by an internal combustion engine (ICE). Diesel engines are typically more efficient than petrol engines, resulting in vehicles that can achieve better mileage and lower carbon emissions. The difference in fuel economy typically becomes more pronounced the larger the vehicle.

As discussed in Chapter 1, the efficiency of conventional vehicles has improved dramatically as a result of improvements in technology, driven by regulatory standards. The 2015 target for new cars sold in the EU to achieve average emissions of 130 gCO_2/km was achieved nearly three years early, standing at 119 gCO_2/km in 2013.[39] Some of the main technologies contributing to these continual improvements in efficiency include:

- **Gasoline direct injection:** Direct injection was originally only seen on diesel engines, but is now also available for petrol cars and could reduce the efficiency gap between diesel and petrol (although there are concerns that car-makers are not installing filters to new GDI engines meaning that pollutant emissions could rise compared to previous generations of petrol engines).[40]
- **Turbochargers:** Turbocharging, widely employed in diesel engines today, could also help close the efficiency gap if introduced to petrol engines. For example, in 2011, an experiment on a Fiat 500 equipped with a turbocharger showed that 30% fuel savings could be realised while reducing engine weight by 10% and delivering the same power output.[41]
- **Cylinder deactivation:** ICEs with this feature can automatically deactivate some cylinders when less power is required resulting in reduced fuel usage.
- **Variable valve timing and lift:** This feature allows engines to be downsized and maintain the ability of the vehicles to deliver the same power.
- **Homogeneous charge compression ignition:** HCCI designs combine characteristics of conventional gasoline engines and diesel engines. They promise to achieve diesel engine-like efficiency with gasoline engine pollution emissions.
- There is also potential to improve efficiency through improvements in **aerodynamics** and the use of **lightweight materials** such as aluminium and carbon fibre.

Beyond this, in an effort to further reduce emissions from conventional vehicles, car manufacturers have begun to add hybrid-electric features, which can be categorised as follows:

- **Micro hybrids** have minor hybrid features such start-stop systems that automatically shut off the engine when idling and therefore allow for fuel saving.
- **Mild hybrids** have small batteries that cannot propel the vehicle on their own, but can assist the engine at times of high power usage. This can be combined with regenerative braking where kinetic energy is used to charge the battery.

39 Note: figures related to test cycle emissions, not real world emissions.

40 Transport and Environment (2013) 'New petrol engines cause more air pollution than dirty diesels'

41 Bohidar, S.K. et al (2015) 'Study of Turbo Charging', *International Journal of Advanced Technology in Engineering and Science*, Volume No 03, Special Issue No. 01, April 2015

- **Full hybrids** have a battery large enough to power the vehicle at low driving speeds, which allows the engine to be completely switched off when driving in heavy traffic. The first generation Toyota Prius is an example of a full hybrid. The ICE and electric motor work in tandem to optimise the vehicle efficiency and performance. (Note: a further step towards hybridisation is plug-in functionality whereby the battery can be charged up directly using grid electricity. Plug-in hybrids are addressed in the following section on ultra-low emission vehicles).

Taken together, these technologies offer significant potential for further improvements in fuel efficiency and carbon emissions. The Committee on Climate Change (CCC) estimates there is potential to achieve a 37% improvement in real world CO_2 intensity for new conventionally fuelled cars over the period 2010 to 2030 (from 171 gCO_2/km in 2010 to 118 gCO_2/km in 2020 and 97 gCO_2/km in 2030).[42] Similarly, there is a potential to reduce CO_2 intensity by 33% for new vans and 24% for new HGVs over the same period. At this rate of improvement, a conventional van sold in 2030 would be more fuel efficient than a conventional car sold in 2010.

Whilst this represents a significant improvement in the efficiency of new vehicles, it will take time for these gains to be rolled out due to the relatively slow churn of the vehicle stock. Only around 6% of the car fleet is scrapped each year and new sales represent around 9% of the existing stock. The average age of the car fleet is 8 years, and this is increasing over time as cars are made to last longer. On this basis, it could take 15 years or more for the full effect of any improvement in the efficiency of new cars to be realised across the entire fleet. In other words, the average CO_2 intensity for new conventionally fuelled cars of 118 gCO_2/km in **2020 could be realised across the entire fleet by 2035. This represents a further 18% efficiency improvement across the fleet of conventional cars compared to today.**

Diesel vehicles tend to be more fuel efficient and emit lower levels of greenhouse gas emissions per mile than petrol vehicles, but they tend to emit higher levels of local pollutants. In a petrol engine, the air/fuel ratio is such that it contains the exact amount of air necessary for a complete combustion of the fuel and therefore emits low levels of pollutants. In diesel engines, the higher air/fuel ratio means that the combustion is unstable and tends to lead to greater emissions of local pollutants unless abatement technologies are used to control this.[43]

Various advances such as ultra-low sulphur diesel fuel, catalysts and particulate matter traps or controls over combustion have already resulted in diesel engines becoming cleaner. The first five generations of European emissions standards (Euro 1 to Euro 5) successfully addressed the Particulate Matter emissions from diesel and petrol cars. The standard for PM emissions from diesel cars was reduced from 0.14 g/km under the Euro 1 standard, to just 0.005 g/km under the Euro 5 standard – a reduction of 96%. This was achieved through the use of particulate filters that almost eliminate PM emissions at little or low cost.[44] As a result of these improvements, PM concentrations have reduced to within the current EU limit.

The bigger issue now is emissions of nitrogen oxides (NO_x). As discussed in Chapter 1, many parts of the UK exceed the legal and healthy limits for NO_2 concentrations, and diesel vehicles are a significant contributor. Progress on

42 Real world emissions, based on an unpublished analysis from Ricardo for the European Commission

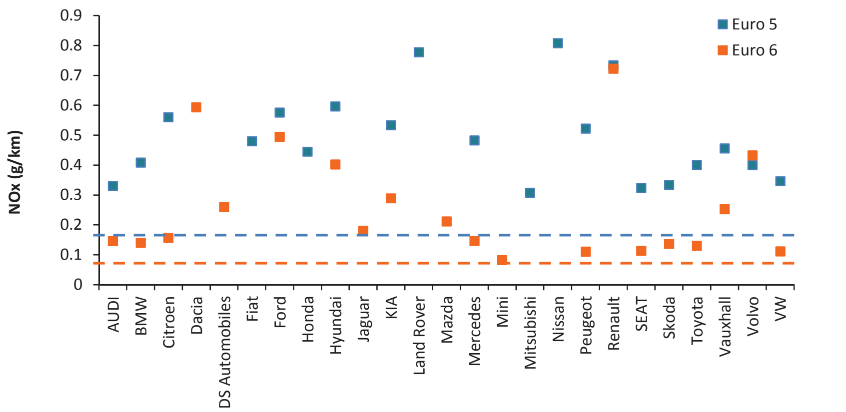
43 ICCT (2014) *Real-world exhaust emissions from modern diesel cars*

44 The Economist (2016) 'The dieselgate dilemma: End of the road for clean, affordable diesel cars?'

reducing NO_x emissions has been slow, despite the introduction of ever tighter Euro standards. This is largely due to the deficiencies in the testing regime, which to date has relied on laboratory testing rather than on the road emissions tests. This is now being rectified with the introduction of a Real Driving Emissions test from September 2017, which will better reflect performance on the road.

Whilst the historic record of NO_x emissions from diesels is poor, there are now positive signs that most car manufacturers are now making progress to reduce these emissions. Figure 2.1 shows data for real-world NO_x emissions for Euro 5 and 6 diesels, summarised by manufacturer.[45] It shows that on the whole, Euro 5 and 6 diesel cars are not performing in line with the required standards on the road – not a single manufacturer is achieving the Euro 5 or Euro 6 limit across its range. However, the chart also shows that almost all manufacturers have made progress in reducing emissions from their Euro 6 models compared to their Euro 5 models. There are also quite a number of manufacturers (Mini, Peugeot, Seat, VW) which are very close to achieving the Euro 6 standard across their fleet – albeit that there are others that perform very badly (e.g. Renault, Dacia, Ford, Volvo).

Figure 2.1: NO_x emissions for different Euro 5 and Euro 6 standard vehicles



The EQUA database published by Emission Analytics provides real world emissions data for individual vehicle models.[46] Again this shows a wide range of performance across makes and models. The best Euro 6 diesels have emissions 20% under the Euro 6 limit – putting them on the par with petrol vehicles, whilst the worst have emissions 20 times the Euro 6 limit. The Department for Transport tested 19 vehicles and found that whilst none of them were under the Euro 6 NO_x standard, there was a trend towards newer Euro 6 models performing better.[47]

Vehicle manufacturers are employing a number of technologies to achieve these improvements:

- **Lean NO_x traps (LNTs)** adsorb NO_x onto a catalyst until it becomes saturated, at which time the system is regenerated and the NO_x is reduced to nitrogen.
- **Selective catalytic reduction (SCR)** reduces NO_x to gaseous nitrogen and water in the presence of ammonia. Most light-duty applications use an aqueous

45 Which (2017) 'From NOx to CO - dirtiest and cleanest carmakers revealed'

46 http://equaindex.com/

47 DfT (2016) *Vehicle emissions testing programme*

urea solution (e.g. 'AdBlue') as an ammonia precursor. This system relies on the user to top up the urea solution.

- **Exhaust gas recirculation (EGR)** attempts to limit the formation of NO_x in the first place by rerouting a portion of the exhaust gas to the combustion chamber to lower the temperature of the fluid and oxygen levels.

Different technologies perform better depending on the whole vehicle design and its use. Overall SCR and EGR systems appear to perform better than LNT systems in terms of real world emissions.[48] However, LNT systems perform well on smaller vehicles and on cold engines, making them especially suited to inner-city driving.

The above options cannot be retrofitted to existing vehicles. One possible retrofit option is to use **hydrogen additive systems**, in which small amounts of hydrogen are added to the air intake to achieve a cleaner combustion process. These systems can be fitted to existing vehicles at minimal cost (£450-650) and achieve both a reduction in NO_x emissions and improvement in fuel efficiency.[49]

Consumer cost/impact

As mature technologies, conventional vehicles with internal combustion engines remain the most affordable to buy today (although this is forecast to change in the 2020s due to reductions in the cost of ultra-low emission vehicles – see Figure 2.4).

As a result of tighter emission standards, manufacturers are incorporating additional features to improve fuel efficiency – usually at minimal cost to the consumer. For example, the ICCT estimates that an emissions standard of 70 gCO_2/km[50] for new cars could be achieved by conventional vehicles and would have an incremental cost per vehicle of between €1,000 and €2,150 in 2025, compared to the 2014 baseline.[51] Full hybrids would be towards the higher end of that range. In addition to this, there will be additional costs involved in making new diesels compliant with Euro standards for NO_x emissions. For example, the ICCT estimate that the incremental cost of upgrading Heavy Goods Vehicles to comply with the Euro VI standard (as opposed to Euro V) is $2,280.[52]

The upfront cost of conventional vehicles is likely to increase somewhat, but this will be offset by improvements in fuel efficiency and the corresponding fall in running costs. A study by Element Energy shows that the Total Cost of Ownership (TCO) of conventional petrol cars is likely to remain flat until around 2020, and then decline as the savings from fuel efficiency outweigh additional up-front costs (see Figure 2.4). The same study shows that the TCO of a conventional diesel car is likely to increase over the period 2015 to 2020, due to the cost of complying with NO_x standards, before declining to 2030. Analysis by the Committee on Climate Change found that the overall cost of reducing van and HGV carbon emissions through efficiency improvements is negative – in the sense that the additional upfront cost is outweighed by fuel savings.[53]

Conclusions

Conventional vehicles and non-plug-in hybrids will continue to make up the majority of new car sales for some time to come, and the majority of cars on the road for even longer. It is important that policies to clean up our transport system acknowledge this, and do not focus exclusively on the adoption of ultra-

48 ICCT (2015) *NO_x control technologies for Euro 6 diesel passenger cars*

49 https://www.cgon.co.uk/Index

50 On a test cycle basis

51 ICCT (2016) *2020–2030 CO_2 standards for new cars and light-commercial vehicles in the European Union*

52 ICCT (2016) *Costs of Emissions Reduction Technologies for Heavy-Duty Diesel Vehicles*

53 CCC (2015) *Sectoral scenarios for the Fifth Carbon Budget*

low emission vehicles. There is still significant potential to improve the efficiency of conventional vehicles, at minimal or negative additional cost to the consumer. Equally, a priority in the short term should be to reduce transport-related NO_x emissions, particularly in urban environments.

Recommendations:

- **Following Brexit, the UK Government needs to urgently clarify the UK's position regarding European vehicle standards and emissions targets.** All vehicles sold in the UK must conform to Euro standards for NO_x and PM emissions, whilst vehicle manufacturers must also conform to fleet-wide CO_2 targets. It is clear that there are substantial flaws in the design of the Euro standards, which have been a contributory factor in the failure to control diesel emissions. Following Brexit, it is unclear whether the UK will continue to conform to these standards and targets, adopt alternative international standards, or create our own set of standards that more accurately reflect the reality of vehicle emissions.
- **Improve vehicle labelling.** At present, vehicle manufacturers are required to display official estimates for fuel efficiency and CO_2 emissions at the point of sale and in advertisements. However, these estimates tend to be wildly inaccurate, as they are based on lab test results (see Figure 2.1). There is currently no requirement to display estimates of NO_x emissions at the point of sale, although this idea was mooted in a recent consultation on Defra's new air quality plan.[54] We strongly support the idea of improving transparency on real world emissions (both CO_2 and NO_x emissions) such that consumers can make more informed decisions about the vehicles they are purchasing. This requirement should ideally apply to both new and second hand cars.
- **Introduce Clean Air Zones in the most polluted cities.** Our previous report, *Up in the Air*, called for a tightening of the restrictions on the most polluting vehicles entering London, which in practice can be achieved through changes to the existing London-wide Low Emission Zone, and the planned Ultra Low Emission Zone. This approach should also be extended to other major cities where it is clear pollution levels will not be addressed without further intervention. For example, Defra data suggests that there are 8 cities or local authorities where NO_2 concentrations will exceed legal and healthy limits by 2023 without further action (London, Leeds, Birmingham, Derby, Nottingham, Cardiff, Southampton, and Halton).[55] We reiterate our position that this needs to be done in a way that minimises the impact on motorists, and gives motorists sufficient warning of any forthcoming changes. We support the Government's position that vehicle charging should only be introduced where it is strictly necessary.
- **Government must ensure that all charging schemes and Clean Air Zones correctly target the most polluting vehicles.** The 'Toxicity Charge', introduced by the Mayor of London Sadiq Khan, fundamentally fails to meet this requirement. As currently designed, all pre Euro 4 vehicles entering Central London will be subject to an additional daily charge from October 2017. However, it is notable that a Euro 3 petrol car (which would be charged) has NO_x emissions substantially below that of a Euro 4 or 5 diesel car (which would not be charged). The T-Charge scheme fails to meet its stated objective of

54 Defra (2017) *Improving air quality in the UK: tackling nitrogen dioxide in our towns and cities*

55 Ibid.

charging the most polluting vehicles. Central Government and Local Authorities must work together to ensure that all charging schemes are designed correctly and based on the best available evidence on real world emissions. Given the deficiencies of the Euro standards scheme, Government should consider basing Clean Air Zones on actual real world emissions data (see point on vehicle labelling above) rather than the inaccurate Euro classifications.

- **Introduce a targeted Vehicle Scrappage/Retrofit Scheme.** Alongside the introduction of Clean Air Zones, the Government should also consider creating a targeted diesel scrappage scheme to take the most polluting vehicles off the road. Defra has modelled this as an option in its recent consultation, but largely discounted it on the basis of it having only a minimal impact on emissions. However, this is due to the fact that Defra assumed a very small scheme (15,000 vehicles) and assumed that scrappage grants would need to be high in order to shift motorists directly from diesel to ultra low emission vehicles. Government should consider a larger scrappage scheme, as well as alternative options such as allowing motorists to scrap a vehicle in exchange for subsidised access to a car sharing scheme, or offer grants for retrofit of vehicles (e.g. hydrogen fuel additive systems or LPG conversion).

Ultra-low emission vehicles

The widespread uptake of ultra-low emission vehicles (ULEVs) is an important cornerstone of the decarbonisation of road transport. ULEVs are defined as vehicles having tailpipe emissions below 75 gCO_2/km[56], and can be grouped into the following categories:

Battery electric vehicles (BEVs) have no engine and are solely propelled by an electric motor using one or more on-board high-power batteries. These vehicles are not a new invention: the first BEVs were developed in the mid-19th century, decades before the first internal combustion engine vehicles appeared on the market. The market for battery electric vehicles remained very small until recently[57], but improvements in battery technology, falling costs and generous government subsidies increased yearly sales from virtually zero in 2010 to tens of thousands in 2016. The most popular model is the Nissan Leaf, which currently costs £16,680 (after a £4,500 government grant) and has a quoted range of up to 155 miles per charge.

Plug-in hybrid electric vehicles (PHEV) have components of both pure battery electric and of conventional internal combustion engine powered vehicles that can be combined in different ways. PHEVs have a battery, but it tends to be smaller as it is combined with an ICE. In electric-driving mode, the energy efficiency of the propulsion system is much higher, and is comparable to that of a BEV. PHEVs also have a long range due to the back-up conventional engine and tank of fuel.

There are many different PHEV designs and one way of categorising them is to look at their driving modes. All PHEVs tend to be capable of charge-depleting and charge-sustaining modes. In charge-depleting mode, the electric motor is used for propulsion and the ICE is switched off until the battery is depleted. In charge sustaining mode, usually when the battery has been fully depleted, the combustion engine starts either to charge the batteries (series hybrid) or to power the vehicle (parallel hybrid). Many PHEV designs also allow a combination of these modes. Some PHEVs are designed so that the electric motor and ICE constantly work in tandem to optimise vehicle performance. For example, the electric motor can be

56 Leaseplan (2017) *Ultra-Low Emission Vehicles White Paper*

57 ICCT (2016) *Electric vehicles: Literature review of technology costs and carbon emissions*

used to propel the car at low speed and the ICE takes over when the car battery is depleted or when the car is cruising (i.e. on the motorway) when the internal combustion engine is most efficient. Both the ICE and the electric motor can even work at the same time to give an extra boost when strong acceleration is required. As such, the electric motor and the ICE can both propel the vehicle separately or together. These vehicles, which are often referred to as blended or parallel plug-in hybrids, tend not to be designed to run on electric power for very long and so have a very limited electric-only range. For example, the 2017 Toyota plug-in Prius will have an electric-only range between 30 and 35 miles.

In contrast, in some PHEVs the ICE will *only* operate when the battery is depleted. These are referred to as **extended-range electric vehicles (EREVs)**. In this case, the ICE turns a generator that can either charge the batteries or power an electric motor that drives the transmission, but the engine never directly powers the vehicle and the propulsion technology is always electric. The ICE acts solely as a range-extender. EREVs tend to have a longer range of between 40 and 100 miles before the ICE is required.

Fuel cell electric vehicles (FCEVs) are often seen as a completely different technology from battery electric vehicles, but in reality they are similar, since both are propelled using an electric motor. The main difference is how they store energy: instead of storing electrical charge in a battery, FCEVs store hydrogen as a compressed gas (or potentially as a cryogenic liquid). The hydrogen is combined with oxygen in a fuel cell to produce electricity, which then powers an electric motor, just like a BEV. The only by-product of this reaction is water.

At present, ULEVs of all types remain a niche part of the car market. At the end of 2016, a total of 96,000 ULEVs had been licensed in the UK, 85,000 of which were cars, plus 5,500 vans.[58] Sales of ULEVs have increased year on year, to 40,000 in 2016 – however, this still represents only 1.3% of all vehicle sales.

Many forecasters predict the take-up of ULEVs to accelerate rapidly in the coming years. For example, the latest BP Energy Outlook predicts the adoption of electric cars to increase 100-fold over the next 20 years, from one million worldwide on the roads today to 100 million in 2035.[59] This is a sizeable increase on its last year projections of 70 million electric cars by 2035. National Grid forecasts the total number of battery electric vehicles on the road to reach 0.2-0.7 million by 2020, increasing to 1.2-5.8 million by 2030.[60]

Emissions reduction

When considering the greenhouse gas emissions associated with ultra-low emission vehicles, it is important to first make a distinction between **direct and indirect emissions.**

Direct emissions, or 'tailpipe emissions' are those associated with the burning of a fossil fuel in a vehicle. When vehicle manufacturers quote figures for carbon emissions, they relate to direct, tailpipe emissions only. The extent of tailpipe emissions from ULEVs depends very much on the technology. BEVs and fuel cell electric vehicles have zero emissions at the tailpipe (in fact a BEV does not even have a tailpipe) whereas PHEVs emit some CO_2 through the tailpipe, depending on the ratio of battery versus engine usage.

Indirect fuel emissions are those involved in the production of the fuel, and again these vary depending on the technology:

58 DfT (2016) *Vehicle licensing statistics: January to March 2017*

59 Business Green (2017) 'BP Energy Outlook cuts emission projections and boosts EV expectations'

60 National Grid (2016) *Future Energy Scenarios 2016*

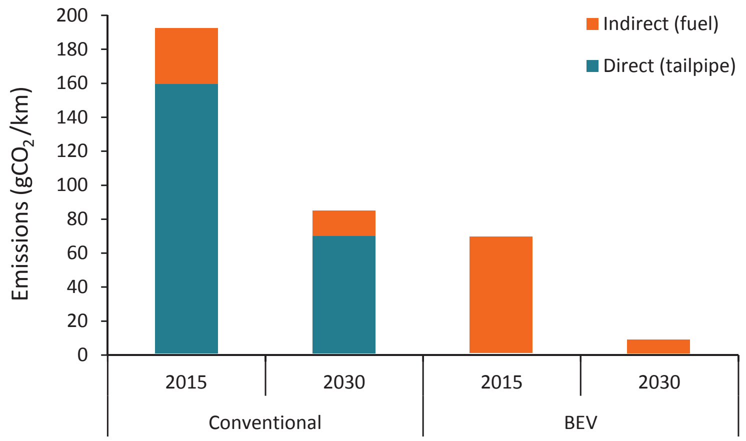
- BEVs have indirect emissions associated with the production of electrical power to charge the battery, and are therefore highly related to the carbon intensity of the grid (e.g. whether power is generated by fossil fuel or low carbon sources).
- For FCEVs, the indirect emissions relate to the production and distribution of hydrogen.
- For PHEVs, the indirect emissions will be a combination of those involved in the production, refining and distribution of the liquid fuel (usually petrol) and those involved in the generation of electricity to charge the battery.

Whereas these non-tailpipe emissions are marginal for conventional vehicles, they can be significant for ULEVs. As we transition from conventional vehicles towards ULEVs and other vehicle technologies, it will become increasingly important to take indirect emissions into account when comparing the 'greenness' of different vehicle types.

As part of this study, we have constructed a model to compare the direct and indirect emissions associated with conventional vehicles and ULEVs. Figure 2.2 shows the results of this analysis, in terms of the total direct and indirect emissions per kilometre. For consistency, a Volkswagen Golf has been chosen in all cases, but with different propulsion systems (BEV = e-Golf, conventional vehicle = Golf GTD 2.0 TDI 184PS 6spd 5dr). Box 1 explains the methodology behind our analysis.

Figure 2.2 shows that for 2015, the conventional Golf has direct emissions of 158 gCO_2/km plus indirect emissions of 33 gCO_2/km associated with the production of diesel fuel. By contrast the BEV version of the same vehicle has zero direct emissions and indirect emissions of 68 gCO_2/km associated with the generation of power used in the vehicle. **In other words, in this example the BEV has total emissions less than half of that of a conventional diesel.** It is expected that the fuel efficiency of conventional vehicles will continue to improve between now and 2030 (see previous section) reducing both direct and indirect emissions. However, the reduction in emissions for the BEV will be even greater due to the expected decarbonisation of the power system in Britain as low carbon sources such as wind, solar and nuclear are added to the generation mix. **By 2030 the emissions from the BEV will be one tenth of a conventional diesel.**

Figure 2.2: Current and projected tailpipe and indirect fuel emissions for different vehicle types



Box 1: Methodology

In the calculations for Figure 2.2, we consider both direct emissions at the tailpipe and indirect emissions from fuel production. Indirect emissions associated with the manufacture of the vehicle have not been considered. The years 2015 and 2030 have been chosen to give an indication of how emissions are likely to change in the future. For 2015 conventional and plug-in hybrid vehicles, direct emissions have been calculated by multiplying official lab-based estimates of emissions by a real world factor of +40%, which corresponds to the average divergence between manufacturers' type-approval and real-world CO_2 emissions.[61] The 2030 fuel consumption figure has been calculated on the basis of official emissions of 50g CO_2/km (NEDC)[62]. Indirect emissions were calculated using Defra emission factors for the greenhouse gas emission from fuel production, used for company reporting.[63] The emissions from electricity generation were calculated using 2015 average carbon intensity and the projections made by the CCC for the 5th carbon budget for 2030.

Figure 2.3 shows that direct emissions from PHEVs vary greatly depending on how they are used, and the proportion of energy which comes from charging the battery from the grid versus using petrol in the ICE. In order to show this we have modelled the carbon emissions from three different electricity to petrol ratios. The emissions from electricity generation were calculated using 2015 average carbon intensity and the projections made by the CCC for the 5th carbon budget for 2030.

The emissions associated with PHEVs are more complicated to estimate because they vary depending on the type of plug-in hybrid vehicle and how it is used. PHEVs vary significantly in terms of how far they can travel in all-electric mode, and their relative fuel efficiency when driving on conventional fuel. User behaviour is also a significant factor, in terms of the balance between long-distance and short-distance trips, and user charging patterns (i.e. the balance between use of electricity versus petrol).

Testing in real-world conditions showed that PHEVs perform almost as well as BEVs when in all electric mode in urban settings. However, PHEVs perform worse than conventional vehicles if they have to run with the ICE only – for example, if the user does not charge the batteries, or when cruising on longer journeys.[64]

Figure 2.3 shows how direct and indirect emissions vary, depending on whether electrical power corresponds to 20%, 50%, 80%, or 100% of total usage. **If a PHEV is rarely charged (e.g. 20% of total usage is electric), then it is little better than a conventional vehicle.**

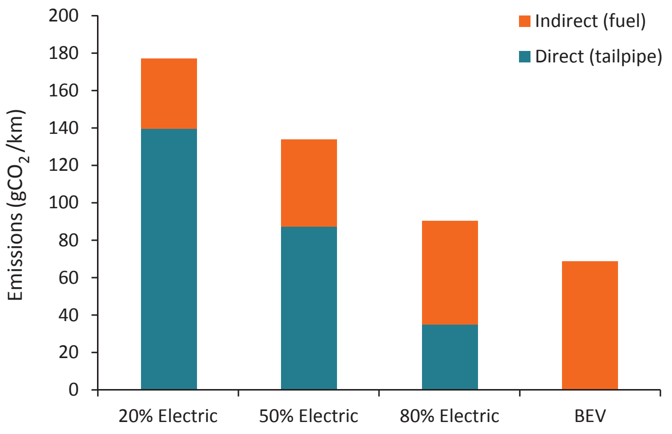
61 ICCT (2015) *From Laboratory to Road: A 2015 update of official and "real-world" fuel consumption and CO2 values for passenger cars in Europe*

62 ICCT (2016) *2020–2030 CO_2 standards for new cars and light-commercial vehicles in the European Union*

63 DECC/Defra (2016) *UK Government GHG Conversion Factors for Company Reporting*

64 Element Energy (2015) *Quantifying the impact of real-world driving on total CO_2 emissions from UK cars and vans: Final report for The Committee on Climate Change*, ICCT

Figure 2.3: Total emissions from an EREV (Golf-GTE) in different driving modes compared with those of a pure battery electric vehicle (e-Golf)



As well as the type of vehicle and charging behaviour, it is also important to consider how the electricity or hydrogen used in ULEVs is produced. For example, analysis shows that a BEV using electricity generated by burning coal would not achieve any emissions saving compared to a conventional vehicle, but as the electricity grid is decarbonised then there would be an increasing saving.[65] The relative emissions saving associated with a BEV will increase as the power grid is decarbonised (e.g. by 2030).

In some locations such as the US, the carbon intensity of the grid varies by location or state.[66] For example, the emissions from a 2017 Volkswagen e-Golf used in California would be 105 gCO_2/km whereas in Michigan the emissions from the same vehicle would be 239 gCO_2/km (see Box 2). In the UK, the variation in carbon intensity is not so great due to the fact that we have a single electric power grid. However, individuals and businesses could reduce the effective carbon intensity of their battery electric vehicles by charging them directly from solar installations.

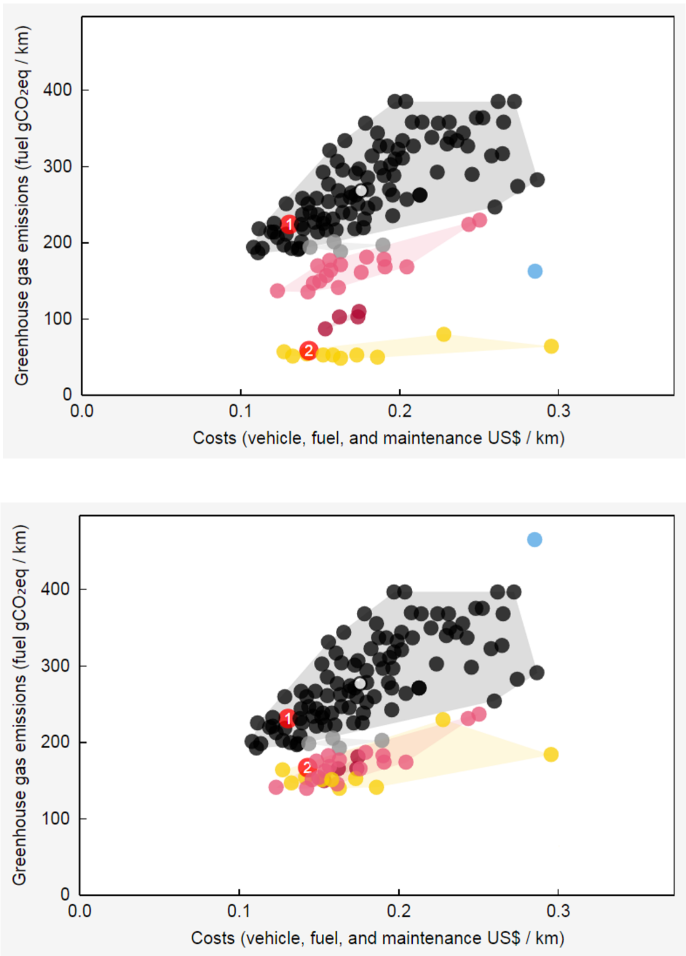
The same considerations are important in the case of a FCEV running on hydrogen. If the hydrogen is produced via electrolysis using a low carbon source of electricity, then the total emissions from using the vehicle would correspondingly be low. However, currently most hydrogen is generated using fossil fuels, typically by reforming natural gas and stripping out the CO_2 (see discussion below on options to produce hydrogen).

65 Wilson, L. (2013) 'Shades of Green: Electric Cars' Carbon Emissions Around the Globe, Shrink that Footprint'

66 Union of Concerned Scientists (online tool): 'How Clean is Your Electric Vehicle?'

Box 2: Varying fuel-related carbon emissions in the USA

Figures (a) and (b): Total 4-year ownership costs versus fuel-related CO_2 emissions for 125 popular cars in the USA[67]

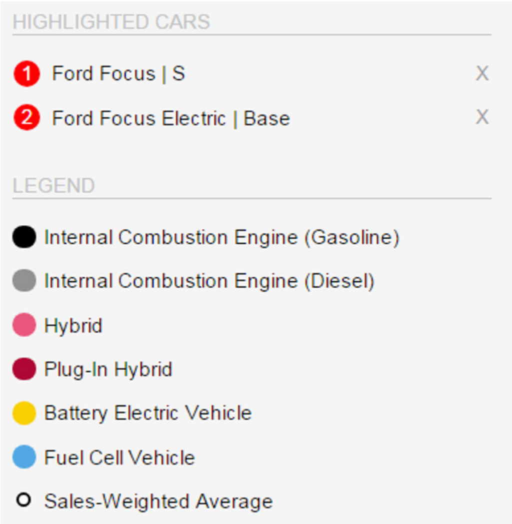


Figures (a) and (b) show the importance of the carbon intensity of the local electricity grid to total carbon emissions. A research team at MIT created an online app that can be used to compare the cost and emissions related to 125 popular vehicles sold on the US market. The x-axis shows the 4-year Total Cost of Ownership for each car (assuming zero direct subsidies), whilst on the y-axis are the fuel-related greenhouse gas emissions.

Figure (a) shows results based on California's electricity grid, which is largely based on natural gas and renewable energy, whilst Figure (b) shows results based on the Midwest electricity grid (MRO), which is heavily based

67 Carboncounter.com (online tool): 'Cars evaluated against climate targets'

on coal power generation. A BEV used in the Midwest area is little better than a conventional ICE vehicle, whilst a BEV used in California achieves a significant emissions saving compared to a conventional vehicle.



To highlight a directly comparable vehicle, the red dots '1' and '2' are for a conventional Ford Focus S and Ford Focus Electric. An unsubsidised Ford Focus Electric is still slightly more expensive to run, but the gap is closing and generous subsidies exist in California to incentivise their uptake.

The singular blue dot on both figures is the hydrogen-fuelled Toyota Mirai. There are various ways of producing hydrogen but we assumed electrolysis production at a projected cost of $8/kg. As can be seen by Figure (b), producing hydrogen from electricity that has been produced from coal power generation is a very carbon intensive process – making the fuel cell car more carbon intensive than a conventional car in this case.

Overall, it is clear that there is potential for ULEVs to achieve a very significant reduction in emissions (both greenhouse gas emissions and local pollutants). However, it should not be taken for granted that this will be the case, and it will be important to consider both direct and indirect emissions associated with these vehicles.

The current system for rating vehicles according to their direct tailpipe emissions alone will become increasingly inaccurate and misleading as we move towards a mix of vehicles using diesel, petrol, electricity, hydrogen, and other fuels. For example, BEVs have zero direct emissions, but do have indirect emissions associated with power generation. The problems with the current rating system have been compounded by the fact that official figures systematically underestimate real-world emissions (see Chapter 1). This problem cannot simply be ignored, since official emissions figures are used as the basis for many different fiscal incentives such as Vehicle Excise Duty, Company Car Tax, and Enhanced Capital Allowances.

Recommendations:

- **The Department for Transport should develop a new system for rating vehicle emissions, which takes into account both direct and indirect emissions.**

Consumer cost/impact

ULEVs have come a long way in the last decade. When modern battery electric vehicles first appeared on the market in the 2000s, they generally suffered from a bad reputation because they had a limited range, poor performance, and were expensive to buy in comparison with conventional vehicles. The 2008 model of the G-Wiz, for example, had a top speed of 50 miles per hour and could travel just 50 miles on a single charge.[68] Today, the technology has improved significantly. In a dramatic demonstration of this improvement, the Rimac Concept One supercar beat one of fastest petrol cars in the world, the LaFerrari, in a specially arranged drag race in 2016.[69] A Chinese-built electric supercar recently completed the fastest ever lap of the Nurburgring race track in Germany – faster than any conventionally-fueled vehicle to date.[70]

Most auto manufacturers now offer ULEVs as part of their range. Manufacturers have managed to extend the range of most new BEVs to 100 miles or more – addressing the initial concerns regarding their limited range. This is already more than sufficient to cope with most car journeys (e.g. the average commute in England and Wales is around 15 km).[71] Several high-end BEV models, due to be released in 2017, will have a range of 300 miles or more, which is comparable with the range of many conventional ICE vehicles on a single tank of fuel.

ULEVs are still more expensive to buy than vehicles powered with fossil fuels, but thanks to dramatic cost reductions in batteries, several models can now be purchased for less than £20,000. The CCC expects electric cars, vans, small HGVs and buses to become cost-effective in the mid-2020s.[72] A recent pan-European study by Element Energy suggested that the cost of BEVs and PHEVs is rapidly converging with that of conventional cars. As shown by Figure 2.4, the 4-year Total Cost of Ownership for a medium-sized BEV is already below that of a conventional petrol car, and the cost of BEVs and PHEVs will be less than €2,000 above that of a conventional diesel car in 2020, even before grants or subsidies for the purchase of these vehicles are taken into account (Figure 2.4).[73] The data in Figure 2.4 relates to medium-sized cars, but the report suggests a very similar pattern for small cars, with near convergence by 2020. For large cars, BEV models are already cheaper than petrol models (albeit that few BEV models are available) and the cost of both BEVs and PHEVs is expected to be within €2,000 of conventional diesel models by 2020.

68 REVA Electric Car Company (2004) 'The Reva'

69 Autoblog (2016) 'Watch Rimac's Concept One roast a LaFerrari and Tesla Model S in a drag race'

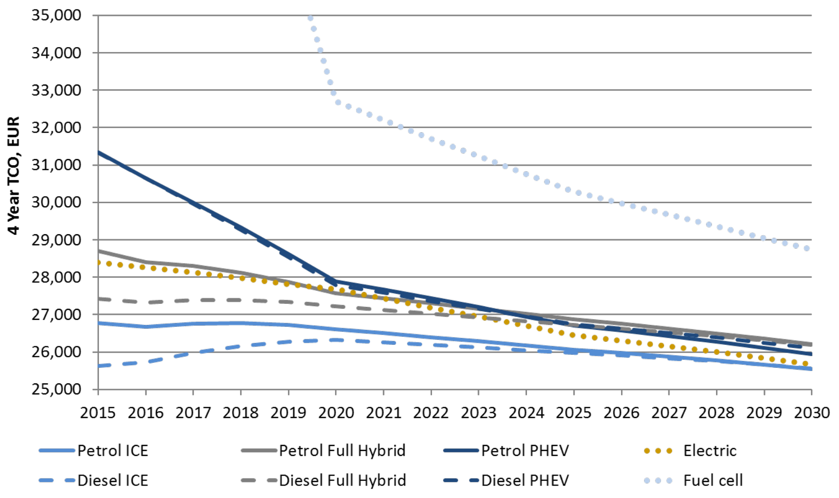
70 City.am (2016) 'NIO EP9 video: Nurburgring record breaking lap by £1.4m Chinese electric supercar'

71 ONS (2014) *2011 Census Analysis - Distance Travelled to Work*

72 CCC (2015) *Fifth Carbon Budget*

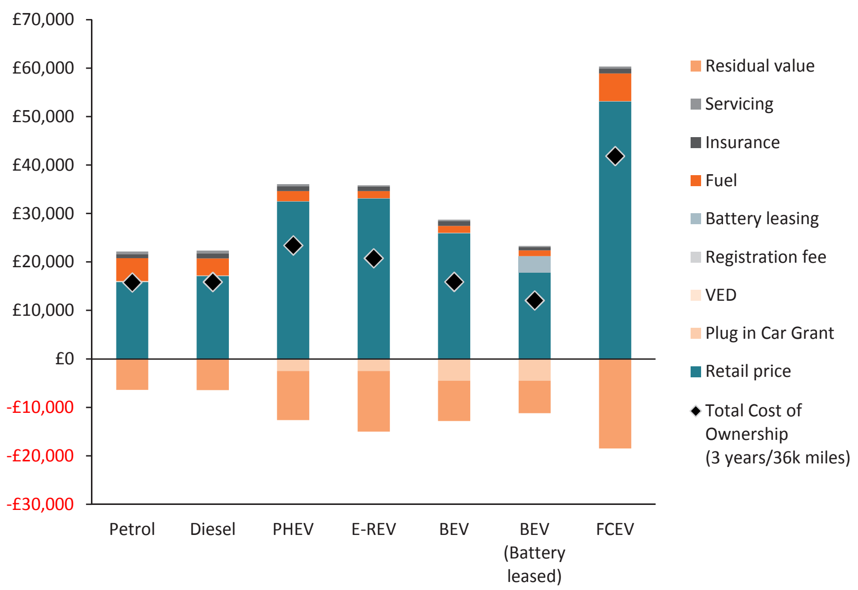
73 Element Energy (2016) *Low carbon cars in the 2020s: Consumer impacts and EU policy implications*, Final report for BEUC (The European Consumer Organisation)

Figure 2.4: Cost curve for different vehicle technologies (Medium Cars – C, D&E Segments)[74]



Currently, it is possible to obtain a grant of up to £4,500 for the purchase of a BEV in the UK, or £2,500 for a PHEV (see Box 3 for a description of current fiscal incentives for ULEVs in the UK). A study by the SMMT found that once these grants are taken into account, the 3-Year Total Cost of Ownership of a BEV is already below that of a conventional petrol or diesel car.[75] There are a range of additional benefits available for ULEVs used in London (where they are exempt from paying the Congestion Charge) or as a company car (where a reduced rate of Company Car Tax is payable), which make the economics even more favourable.

Figure 2.5: Four year Total Cost of Ownership of different vehicles types



74 Ibid.

75 SMMT (2016) *Ultra Low Emission Vehicles Guide*

By contrast, FCEVs are still considerably more expensive than conventional vehicles or BEVs. They are expected to remain more expensive throughout the 2020s, although the cost differential is expected to decrease substantially by 2030 (Figure 2.4). This is likely to limit the uptake of hydrogen-fuelled cars for the time being, unless more substantial reductions in cost can be achieved through greater economies of scale.

Recommendations:

- **Government needs to continually review the system of grants for ULEVs to ensure that it is obtaining value for money.** The analysis presented here suggests that the current subsidy to BEVs makes them cost-competitive with conventional vehicles. The Government should signal a phase out of grants for BEVs and PHEVs (cars) by the early 2020s, by which time cost reductions will mean that they are cost-competitive with conventional vehicles in the absence of grants. There will be an ongoing need for Government to support the uptake of FCEVs well into the 2020s. However, Government should cap the total grant funding available for FCEVs to avoid over-subsidising this technology at a relatively early stage of maturity.

Beyond cars, light vans are likely to be the next vehicle type where ULEVs are a viable option. Light vans with a range of around 100 miles are already on the market, including the Citroën Berlingo and the Nissan E-NV200. Analysis by the Freight Transport Association found that one third of light vans never travel more than 80 miles in a single day[76], meaning that the limited range of electric vans is an issue for some but not all van drivers. Electric vans are still significantly more expensive to purchase than diesel equivalents, but due to Government grants (see Box 3) and lower fuel costs, they are already attractive on a Total Cost of Ownership basis. The LowCVP compared a Nissan N200 1.5dCi Acenta with a Nissan e-NV200 Acenta and found that, although the diesel on-the-road price is £7k cheaper, the six year ownership cost of the electric van is £4,514 lower than the diesel model, rising to £17,639 if used daily in London (due to the congestion charge exemption for low emission vehicles).[77]

Hydrogen-powered light vans are currently unattractive due to much higher costs. The LowCVP study quotes the cost of a Kango Maxi 1.5 dCI diesel van as £15,296, with its hydrogen equivalent (the HyKangoo ZE Maxi) costing £45,899.

There are just 4,500 electric vans (including plug-in hydrids) on UK roads[78], but with such cost savings available and new models being released, this number can be expected to rise in the coming years.

The powering of heavier vans with electric batteries is still a challenge due to limited range. The current weight of batteries may present a problem. In addition to this, a standard UK driving licence allows people to legally drive vehicles up to 3.5 tonnes. Above this requires a C1 larger goods vehicle licence. Battery packs for electric vehicles are currently much heavier than an equivalent ICE engine so delivery companies wanting to use larger electric vans could find that their employees are not qualified to drive the electric vans, at least until technology develops far enough to bring the weight down. There are, however, exemptions for certain vehicles that allow people with a standard licence to drive them.[79] The Government should investigate whether such exemptions for electric vans are necessary and whether this would present an increased risk to public safety.

76 https://vans.honestjohn.co.uk/how-to-buy-and-sell/should-i-buy-a-petrol-diesel-or-electric-van/

77 LowCVP (2016) *The Low Emission Van Guide*

78 Next Green Car (2017) 'Electric car market statistics'

79 NI Direct (2017) 'Driving larger goods vehicles (LGV) on a car driving licence'

Box 3: Summary of Fiscal Incentives for Ultra-Low Emission Vehicles

- **Plug-in car, van and motorcycle grants:** These subsidies currently cover up to 35% of the upfront cost of an ultra-low emission car (up to a maximum of either £2,500 or £4,500 depending on the model), 20% of the cost of a van (up to a maximum of £8,000), or 20% of the cost of a motorcycle (up to a maximum of £1,500).
- **Vehicle Excise Duty (VED) reductions:** At the time the OLEV strategy was written, there was an exemption or significant reduction in the VED (or 'road tax') levied on cars emitting less than 120 gCO_2/km. It was claimed that sticking with this system would have meant that 75% of new cars would have exempt from road tax by 2017. The system was subsequently overhauled in Budget 2015, such that from April 2017 onwards only cars with zero tailpipe emissions are exempt from VED.
- **Company car tax (CCT) reduction:** To stimulate the uptake of ULEVs, they were subject to an exemption or reduction in the amount of Company Car Tax payable. From 2010 until 2015, cars with zero tailpipe emissions were exempt from Company Car Tax, whilst cars emitting less than 75 gCO_2/km were subject to 5% CCT (compared to 11-35% for conventionally fuelled cars with higher emissions). The system was reformed to raise the CCT bands both for ULEVs and conventionally fuelled vehicles. By 2018-19, the CCT rates will be 13% for cars emitting 0-50 g CO_2/km, compared to 19-37% for conventional vehicles.
- **Capital allowances:** businesses purchasing low emission vehicles are able to access 100% first year capital allowances.
- ULEVs do not pay any fuel duty, since this is charged only petrol and diesel, but not electricity.
- The VAT levied on electricity (5%) is far lower than the standard rate of VAT levied on petrol and diesel (20%).

A number of further benefits for ULEV drivers have also been introduced in different parts of the country, including:

- **London Congestion Charge exemption:** Exemption from the £10 per day charge for vehicles that are either pure electric or that emit 75 g/km or less of CO_2 and meet the Euro 5 emission standard for air quality.
- **Discounted parking:** Local authorities are operating a range of schemes to provide discounted or even free parking for ULEVs. Parking for residents, visitors and businesses are included.
- **Traffic restriction exemptions:** A number of cities are reviewing options for future restrictions on traffic in key hotspots to reduce congestion and improve air quality. A ULEV exemption is being considered as part of several of these.
- **Grants for ULEV taxis:** York currently operates a discount from their taxi licensing fee for hybrid and electric taxis that emit 100 g/km or less of CO_2, and also offers a grant to assist with vehicle purchase.

Infrastructure cost/impact - BEVs

This section explores the infrastructure issues involved in a roll-out of electric vehicles and focuses mostly on battery electric vehicles as they would present the most significant infrastructure challenges. PHEVs can be assumed to present similar issues, but on a smaller scale (since they can also use liquid fuels). From a policy point of view, the whole energy system must be taken into account, from the availability of individual charging points, to the impact on local electricity networks and the national transmission network, to consideration of the extra generation capacity required to cater for the increased demand for electricity. The widespread roll-out of battery electric vehicles could present challenges (and opportunities) across this entire system.

Charging points

It was previously thought that a limiting factor to the roll-out of BEVs could be the availability of sufficient charging infrastructure - in part driven by a perceived 'range anxiety'. In practice the roll-out of charge points has more than kept pace with the increase in vehicle sales, whilst manufacturers have increased the range of BEVs, reducing the frequency of charging needed. However, if there is to be a widespread roll-out of BEVs then a significant expansion in the number of charge points across the UK would still be required.

Charge points can be located at home, at workplaces, at the roadside or at dedicated rapid charging stations. They can be categorised by the time they take to fully recharge a vehicle: slow chargers are the least expensive (around £1,000) and take 6-8 hours to fully recharge an electric car,[80] whilst rapid chargers can cost up to £30,000, but can charge a battery to 80% capacity in just half an hour.[81]

The number of on-street charge points has grown substantially in the last five years and there are now over 12,000 on-street charge points spread across 4,000 locations, including a growing number of rapid chargers (Figure 2.6).[82] Government has made a series of investments to accelerate the roll-out of charging points and has mandated that all rapid charge points that receive public funding must cater to the three most common current standard designs (CCS, BYD, and Chademo).[83] OLEV has made installing rapid charge points in service stations across the country a priority and has allocated £80 million over this Parliament to incentivise their deployment.[84] Highways England is also investing £15m to ensure there is a charge point at least every 20 miles on the Strategic Road Network, whilst the Government say they are open to the idea of mandating charge points at certain important hubs, like large service stations.[85] Government also invested £30 million in eight regional schemes to roll-out charging infrastructure, through the **'Plugged-In Places'** initiative, a further £40 million through the **'Go Ultra Low Cities Scheme'** (which offered grants to four main cities for charging infrastructure, as well as free parking for ULEVs) and a further £2.5 million in grants to Local Authorities for on-street charging points.[86] In addition to this, the Government has provided grants of up to £500 for the installation of a home charger, with around 70,000 installations completed to date.[87]

80 Zap-Map (2016) 'Charging Basics'

81 DfT/OLEV (2016) *Proposed ULEV measures for inclusion in the Modern Transport Bill*

82 Fleet News (2016) 'Charging infrastructure 'keeping pace' with EV uptake'

83 OLEV (2014) *Investing in ultra low emission vehicles in the UK, 2015 to 2020*

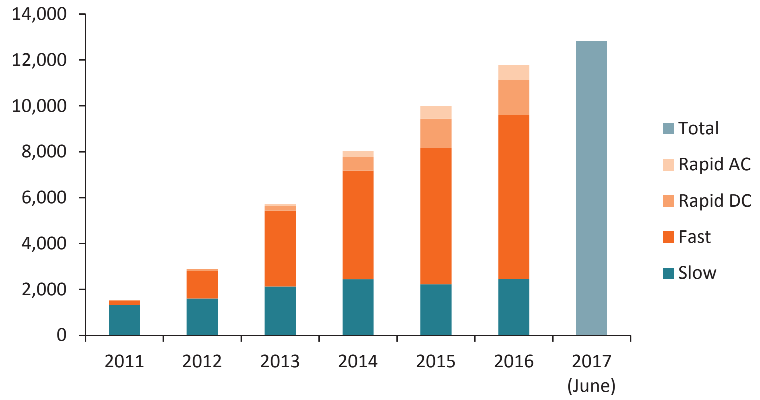
84 John Hayes MP (2017) 'All-Party Parliamentary Design and Innovation group address'

85 DfT (2016) *Proposed ultra low emissions vehicles measures for inclusion in the Modern Transport Bill - Government response*

86 OLEV (2016) *Grants to provide residential on-street chargepoints for plug-in electric vehicles – Guidance for Local Authorities*

87 Source: OLEV, unpublished data

Figure 2.6: Public charging connectors in the UK by type, 2011-2016 (data from Zap Map)[88]



Whilst the number of public charge points is growing rapidly, there is evidence that this infrastructure is being under-utilised. This may be in part due to the fact that BEVs still only make up a small proportion of the total UK fleet, and utilisation may grow as the number of battery electric vehicles on the road increases. However, early indications are that most BEV owners choose to charge their vehicle at their home or workplace rather than on-street charge points - locations where a vehicle can be left for long enough for a full charge on a regular basis.[89] Analysis for the Department of Transport found that 97% of battery electric vehicle owners had the ability to charge their car at home, and that the vast majority of charging events occurred at home, followed by the workplace.[90] A study by Element Energy[91] found that 70% of car owners in suburban areas and 50% of those in urban centres have off-street parking with enough space for their own dedicated charge point, and the percentage is much higher for rural properties, so the availability of home charging is not a limiting factor in the near-term.

Advocates have defended investment in on-street charge points (despite their low utilisation) on the basis that this investment was necessary to promote BEVs to a sceptical public and to allay fears about the lack of charging infrastructure. BEV drivers still consistently express a desire for more extensive public charging infrastructure to enable longer journeys. There may be merit in this argument to an extent, but Government must be careful not to expand the network of public charging points too far ahead of demand, and make sure chargers are focused in the right places. Evidence across different countries suggests low utilisation of roadside slow chargers with drivers expressing a preference instead for more rapid charge points at strategic locations like service stations and destinations like restaurants and hotels. The 2011 OLEV strategy subscribes to this view stating a desire for 'public infrastructure to be targeted at key destinations, where consumers need it, such as supermarkets, retail centres and car parks, with a focused amount of on-street infrastructure, particularly for residents without off-street parking.'[92] However, with roadside charging infrastructure managed at a local level in the UK, this is not completely in the hands of central Government.

88 Zap-Map (2017) 'Chargepoint Statistics 2017'

89 Eurelectric (2016) *Charging infrastructure for electric vehicles*

90 Brook Lynhurst (2016) *Uptake of Ultra Low Emission Vehicles in the UK,* A Rapid Evidence Assessment for the Department for Transport

91 Element Energy (2009) *Strategies for the uptake of electric vehicles and associated infrastructure implications for The Committee on Climate Change Final Report October 2009*

92 OLEV (2011) *Making the Connection: The Plug-In Vehicle Infrastructure Strategy*

Whilst there is a role for Government in 'kick-starting' the development of vehicle charging networks, there is a risk that Government crowds out private sector investment or creates a reliance on subsidy which becomes unsustainable in the long term. Going forward, the Government should aim to create a competitive charging market based on private investment rather than subsidies and grants. Whilst the market for public charge points is still in its infancy, a variety of business models are beginning to emerge, including:

- **Tesla** are building their own supercharging network all over Europe. This has in the past been completely free to Tesla owners, but they are beginning to charge fees.[93]
- **Uber** are beginning to deploy charge points across London, initially exclusive to Uber drivers.[94]
- **Borne Recharge** in France installs charge points in residential underground car parks. Payment automatically links to your electricity bill.[95]
- **Chargie** is a nascent 'Air BnB' style service that allows people to rent out their home charging station.[96]
- Many charge point companies in the UK are also trying to partner with large supermarket chains in order to be first to the market (e.g. Red Point, Charge Master, EO Charging).

Recommendations:

- **Government needs to continually review the system of grants for home, workplace, and on-street charging points to ensure that it is obtaining value for money and not over-subsidising their deployment.** The Government should signal a phase out of subsidies for the installation of charging points by around 2020.
- **Government needs to put in place an appropriate regulatory framework to create a competitive market for charging** (and refuelling stations for hydrogen vehicles). Electric charging infrastructure and services are currently unregulated, creating significant risk for investors and consumers, and should be brought within the remit of Ofgem (the energy regulator).

Networks and smart charging

In their 2016 Future Energy Scenarios report[97], National Grid estimated that there could be up to 9.7 million battery electric vehicles on UK roads by 2040, which would create an additional electricity demand of 24 TWh per year - an increase of 8% from current total electricity demand. Whatever the pace of battery electric vehicle up-take, it is vitally important that upgrades to the electricity system (comprising the transmission grid, local distribution networks, power generation and storage) are made in parallel to accommodate the increase in electricity demand and manage changes in the profile of electricity usage that are likely to arise.

93 Tesla (2017) 'The World's Fastest Charging Station'

94 Engadget (2017) 'Uber is building its own EV charging network in London'

95 www.bornerecharge.fr/

96 www.chargie.net

97 National Grid (2016) *Future Energy Scenarios 2016*

The extent of the impact of BEV uptake on networks and power generation depends significantly on charging patterns and electricity usage. Trials of consumer behaviour in London by Imperial College's Low Carbon Learning Lab have shown that the most common charging patterns (without any policy intervention) are for drivers to plug in an BEV when they get home from work in the evening such that it is fully charged for use the following day. Their study concludes that 'uncontrolled BEV charging results in high peaks that broadly coincide with the existing system peak demand, creating additional stress for the electricity system infrastructure.'[98] This pattern occurred even in some cases when there was a tariff structure which encouraged customers to change their behaviour. A larger scale study of the usage of 711 charge points in Ireland took place from 2012 to 2015.[99] It found that 'EV users prefer to carry out the majority of their charging at home in the evening during the period of highest demand on the electrical grid indicating that incentives may be required to shift charging away from this peak grid demand period.'

This evidence, taken in isolation, suggests that the widespread roll-out of battery electric vehicles *could* have major implications for our electricity system. National Grid, in their Consumer Power scenario[100] estimates that adding 7.9 million battery electric vehicles could add 7 GW to peak demand in 2040 – an increase of more than 10% above current peak demand. In an absolute worst case scenario, if all these vehicles were plugged into 3 kW home charging units at the same time, peak demand would increase by 23.7 GW. Catering for a large increase in peak demand would require significant investment in additional generation capacity, along with grid upgrades (particularly in the local distribution network).

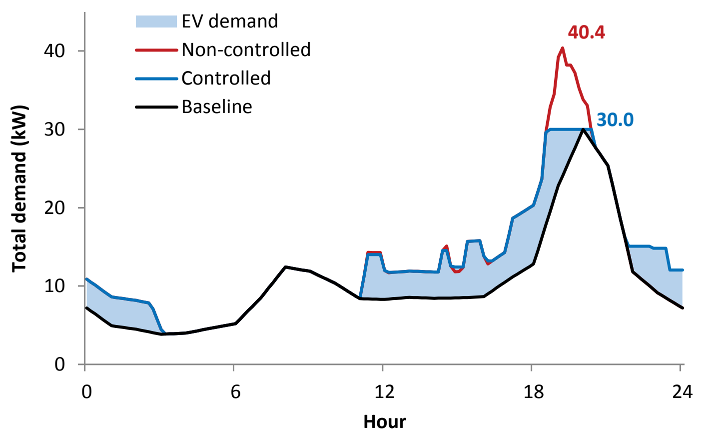
However, the trials by Imperial College showed that smart technology and controls have the potential to manage the additional load without adding to peak demand (see Figure 2.7). The study identified 'significant potential for smart BEV charging to support peak demand management, without affecting the capability of BEV users to make their intended journeys.' This suggests that implementing smart charging strategies will be crucial to ensure an efficient integration of battery electric vehicles into the electricity system. So as long as charge points are smart and controllable, the extent to which investment is required in additional generation capacity and network infrastructure will be reduced. Smart battery charging could even enable a more efficient operation of the power system – for example BEVs could increase their demand during times when electricity supply would otherwise exceed demand (e.g. on sunny days when solar generation is at its highest). At a local level, some businesses have already begun trialling smart infrastructure to optimise the charging of their fleet (see Box 4).

98 Imperial College London (2014) *Impact & opportunities for wide-scale EV deployment*

99 Morrissey, P. et al (2016) 'Future standard and fast charging infrastructure planning: An analysis of electric vehicle charging behaviour', Energy Policy Volume 89, Pages 257–270.

100 This scenario assumes with limited uptake of smart charge management and time-of-use-tariffs

Figure 2.7: Residential electricity demand profiles from a trial of 10 battery electric vehicle users[101]



Box 4: UPS battery electric vehicle roll-out case study[102]

UPS have started to transition their fleet from diesel to battery electric vehicles. UPS wanted to use 50 new electric delivery trucks at a location in London, but found that charging the vehicles whilst also running their sorting systems would exceed the local network capacity – and they would be required to pay to upgrade the local network to cope with the additional demand.

However, they have now partnered with UK Power Networks to trial new smart grid technology. By using a small amount of stationary electric battery storage (equivalent to 3 BEVs) combined with smart control of charging times, they will be able to charge their 50 electric delivery vans without overloading the network. Their oldest battery electric vehicles are eight years old and coming to the end of their working life, but UPS now have plans to make use of their batteries to provide additional onsite storage.

Certain social, technical and policy requirements will need to be met in order to enable smart charging technology and mitigate the impact of BEV charging on the power system, including:

- **Smart meters and half hourly settlement:** A near-term challenge will be that most electricity meters in UK homes are still 'dumb' meters that cannot communicate externally and do not have the capability to record half-hourly usage data[103], which would be necessary for smart charging and control of BEVs. This problem should be rectified with the ongoing roll-out of smart meters across

101 Source: Imperial College London (2014) *Impact and opportunities for wide-scale electric vehicle deployment*

102 Edie.net (2017) 'UPS to trial electric vehicle 'smart grid' in London'

103 Ofgem (2014) 'Electricity settlement – moving to half hourly settlement'

the country, which Government is targeting for completion by 2020 (albeit that achieving universal roll-out by 2020 is looking increasingly unlikely).

- **Time-of-use tariffs:** At present, most households and businesses are charged a flat rate for electricity, regardless of when they use it. In order to incentivise users to shift their charging patterns away from peak times, suppliers will need to implement so-called 'time-of-use tariffs' whereby the price of electricity varies according to the time of day, with higher charges at peak times. The Economy 7 and Economy 10 tariffs are examples of simple time of use tariffs, but currently require each user to have two separate meters. With the advent of smart meters, suppliers will be able to develop more sophisticated time of use tariffs – potentially even responding dynamically to market prices. Whilst time of use tariffs offer great potential in theory, this may be limited to an extent by a lack of consumer engagement. Early trials of smart meters suggest that such tariffs must work automatically in conjunction with smart technology and dynamic pricing, as the majority of consumers are not sufficiently engaged to change their behaviour on their own.[104] The fact the BEV owners will already be making large fuel cost savings compared with the cost of running a petrol or diesel vehicle makes them less likely to respond actively to slight changes in the electricity price. The smart charging of battery electric vehicles must be made as easy as possible, and become the norm. Electricity providers and electric car vendors will need to work with consumers to optimise their charging profiles in a way that saves them money, ensures they always have a charged battery when required, and reduces peak load on the grid.
- **Smart, controllable charge points:** Under the Vehicle Technology and Aviation Bill 2017105, the Government sought to create new regulations requiring all new charging points to be capable of receiving, processing and transmitting information, monitoring energy consumption, and facilitating remote access. The Bill was not completed prior to the election, and has since been replaced by the Automated and Electric Vehicles Bill, announced in the Queen's speech.
- **Data requirements:** In order to create a smart charging system it is vitally important to know where all charge points are located and when they are being used, in order to plan for any necessary power system upgrades, and optimise the system in real time. When solar PV became widespread in the UK, there was no general register of PV systems, so electricity was being fed into the grid from unknown locations creating management issues for distribution network operators (DNOs) and National Grid (as discussed in our recent report, *Power 2.0*).[106] The same mistake should not be repeated for electric charging. Government funded public charge points are required to be put on the National Chargepoint Register[107] and home charge point installers in receipt of a Government grants are also required to notify the local DNO, but there is currently no legislation requiring privately funded charge points to be registered either with DNOs or OLEV. We need to prepare for a future in which there is a wide-scale uptake of privately funded home charge points. In order to ensure grid stability at a local level, the DNOs will need to know the location of all charge points. Ideally, there should be a register of all charge points, public and private, that is accessible to Government, National Grid, and the DNOs.
- **Consumer consent:** Smart charging means that consumers will need to relinquish some control over when their vehicle is charged (in exchange for lower electricity prices). They will also need to be willing to share data on their charging behaviour. It is unclear at this point whether or not consumers

104 BBC News (2010) 'Smart meters 'may not cut energy use''

105 Parliament (2017) *Vehicle Technology and Aviation Bill 2016-17*

106 Howard, R. and Bengherbi, Z. (2016) *Power 2.0: Building a smarter, greener, cheaper electricity system*, Policy Exchange

107 OLEV (2014) *Investing in ultra- low emission vehicles in the UK, 2015 to 2020*

will consent to this. Even if legislation is in place to require consumers to share their data, it is important to convey the benefits to BEV owners of smart charging in terms of reduced electricity bills. Otherwise the perception of government or industry intrusion and control could act as a disincentive to the purchase of an electric car or the sharing of data.

- **Vehicle-to-grid capability:** Finally, it has been suggested that vehicle batteries could be used to feed power back in to the grid at times of high demand. This is often put forward as a potential solution to balance the system alongside intermittent renewable electricity sources (as discussed in our recent report, *Power* 2.0).[108] Vehicle-to-grid capability is not an immediate requirement for the roll-out of BEVs, but is a potential upside that should be explored further. It is unclear whether using vehicle batteries in this way could degrade the batteries at an accelerated rate - this is a highly contested subject with views on both sides. A study by Cambridge University[109] found that vehicle-to-grid functionality would only become useful when there is widespread take-up of BEVs and suggested that the investment in infrastructure is not warranted until that time. However, the potential benefits of vehicle-to-grid should be kept in mind when designing smart grid infrastructure, so as to not place barriers in the way of this opportunity in the future.

Recommendations:

- **OLEV should conduct further research into the public perceptions of smart charging to determine how consumers are likely to respond to time of use tariffs.**
- **Create new regulations, under the Automated and Electric Vehicles Bill, to ensure that all charging points are 'smart' and controllable.**
- **Policy changes are also required to ensure that data is collected on the location and usage of all charge points in the UK (public and private) and this data be made available in an appropriate form to energy suppliers, network operators and Government.**
- **The Institution of Engineering Technology issue guidelines on the installation of home charge points. We recommend that these guidelines, including a requirement to register new charge points with the DNO, be partially incorporated into Part P of the Building Regulations.**

Infrastructure cost/impact – Hydrogen

The UK has begun to incentivise the deployment of hydrogen refuelling stations, but this is at the early stages and they are much less prevalent on our roads than electric charge points. There are currently only 13 in operation and some of these are for research purposes and not open to the public[110], serving only a small number of early adopters of hydrogen-powered cars, vans and buses. This represents a first step towards an initial network of 65 stations by 2020 as recommended by the UKH2 Mobility consortium and supported by the Government's Hydrogen for Transport Advancement Programme.[111] The consortium has set out a roadmap towards achieving full national coverage with 1,150 stations by 2030.[112] Shell, who opened the UK's first fully commercial hydrogen station in February 2017, see a future for

108 Howard, R. and Bengherbi, Z. (2016) *Power 2.0: Building a smarter, greener, cheaper electricity system*, Policy Exchange

109 Weiller, C. and Neely, A. (2014) 'Using electric vehicles for energy services: Industry perspectives', *Energy*, Volume 77, Pages 194–200

110 www.netinform.net (online tool): 'Hydrogen Filling Stations Worldwide'

111 DfT/OLEV (2016) 'Government launches £2 million competition to promote roll-out of hydrogen-fuelled fleet vehicles'

112 SMMT (2016) 'Ultra Low Emission Vehicles Guide 2016', The Society of Motor Manufacturers and Traders Limited

both FCEVs and BEVs and they intend 'to serve both markets by installing battery charging points, as well as hydrogen pumps at some of its filling stations'.

BEVs have a clear head start on FCEVs and part of this is due to the different nature of their infrastructure requirements. Even before public charge points proliferated, any individual could have purchased a BEV and used it quite comfortably for short trips – charging it at home. Things are not so straight forward for FCEVs. Building just one hydrogen fuel station is a large financial undertaking. Building a whole hydrogen transport network before large numbers vehicles are on the road would be a major risk, but it is also a necessary pre-condition of encouraging people to purchase hydrogen vehicles.

Like for BEV infrastructure, it is important to think of hydrogen infrastructure in terms of the whole system, which is comprised of:

1. Hydrogen production
2. Distribution via tankers or pipelines
3. A network of refuelling stations

The first obstacle to creating a hydrogen-based transport system is how to source large amounts of inexpensive, low carbon hydrogen. Hydrogen is already produced in large quantities for use in industrial applications. This is mainly done through a process of 'steam reformation' in which natural gas is split into hydrogen and carbon dioxide. 95% of US hydrogen is produced using this process[113], as it is the least expensive method of production (though this is partially due to historically low natural gas prices). Table 2.2 shows a comparison of the relative costs of producing hydrogen by different means.

The issue is that steam methane reformation is not low carbon: it produces twice as much carbon dioxide as hydrogen.[114] So just as the electricity used to charge battery electric vehicles needs to be from low emission sources for BEVs to be considered low carbon, for a hydrogen fuel transport system to be genuinely low carbon, the industry also needs to find ways to reduce carbon emissions associated with hydrogen production. This can be achieved by capturing the CO_2 produced through steam methane reformation, and permanently sequestering this gas in a depleted oil or gas field (Carbon Capture and Storage or CCS). The downside of this is that it would add significant cost to the process. Also, the prospects for CCS in the UK in the near future are not promising, with the Government having cancelled its £1 billion CCS demonstration programme in 2015.

Japan is leading the way with an ambitious hydrogen vehicle roll-out programme that will source hydrogen produced from the gasification of Australian coal, combining this process with carbon capture and storage in order to limit emissions. The pure hydrogen would then be shipped to Japan in tankers specifically designed for transporting liquid hydrogen.[115]

In the longer term, producing hydrogen through the electrolysis of water, using a renewable or nuclear source of electricity, may offer a potential way of producing large amounts of hydrogen without relying on fossil fuels. However, the cost of electrolysis would need to fall substantially for it to become the dominant production technique. Producing hydrogen via electrolysis for use in a fuel cell will always be less efficient that simply using that electricity to directly charge an battery electric vehicle.

113 www.energy.gov : 'Hydrogen Production: Natural Gas Reforming'

114 New York State Energy Research and Development Authority: 'Hydrogen Production – Steam Methane Reforming (SMR)'

115 *Financial Times* (2017) 'Japan gambles on Toyota's hydrogen powered car'

Table 2.2: The costs of hydrogen production[116]

Technology (scale)	Cost range US$ (2000) per GJ of hydrogen	Notes
Large-scale steam reforming (> 1000 MW)	5 - 7	Highly dependent on natural gas price.
Small-scale steam reforming (<5MW)	12 - 40	Smaller scale production increases costs.
Coal gasification (min. 376 MW)	5 - 7	CO_2 capture and storage would increase these costs.
Large-scale electrolysis (>1 MW)	11 – 75	Cost of electricity is a factor.
Small-scale electrolysis (< 1MW)	28 - 133	Smaller scale production increases costs.

The transport and storage of hydrogen is much more challenging than for most other fuels. Liquid hydrogen at atmospheric pressure must be kept at around -253°C, which is an energy intensive and expensive process.[117] Its low vapour pressure and small molecules also mean that it is very difficult to contain. It has been estimated that in a regular road tanker, liquid hydrogen losses through boil-off amount to between 0.3% and 0.6% per day.[118] Transporting hydrogen via sea in tankers, similar to how the UK imports LNG, is possible. However, due to the lower temperature and higher leakage rate, new, more expensive tankers would have to be designed and built for a global hydrogen market to become a reality. Likewise, the UK has long term storage tanks for LNG and similar tanks could exist for hydrogen if amended to take account of the fuel's more challenging characteristics. For these reasons, for the foreseeable future, hydrogen used for transport in Britain will most likely also be produced in Britain and as close to the refuelling infrastructure as possible.

Recommendations:

- **The Government should commission further research into low carbon hydrogen production, transport, storage and refuelling infrastructure – including how to reduce future costs.**

A shift to hydrogen vehicles would also require a national network of refuelling stations. Cost estimates for hydrogen refuelling stations vary greatly, depending on how the hydrogen is produced and whether it is produced onsite or delivered from a central production site. One recent estimate for Germany put the cost at €1 million per hydrogen refuelling station,[119] but estimates vary from ~€330,000 to ~€5 million.[120] Element Energy suggests that achieving full coverage across Britain would require 1,000 hydrogen fuel stations at a cost of at least a £2 billion. This is what it would take to remove the 'range anxiety' barrier from potential FCEV owners.[121]

Estimates for the overall system-wide infrastructure cost for both FCEVs and BEVs are both highly uncertain at this early stage, but are likely to be of the same

116 Source: Nuttall, W.J. et al (2016) *Next Steps for Hydrogen: Physics, technology and the future*, The Institute of Physics

117 IEA (2007) Hydrogen Production & Distribution, IEA Energy Technology Essentials

118 Garche, J. (2009) *Encyclopaedia of Electrochemical Power Sources*, Elsevier

119 ICCT (2016) *Electric vehicles: Literature review of technology costs and carbon emissions*, quoting Hegmann (2015)

120 ICCT (2016) *Electric vehicles: Literature review of technology costs and carbon emissions*

121 Dominic Tobin (2015) 'The Future of Hydrogen Filling Stations in Britain', *The Sunday Times*

order of magnitude. In analysis of projected costs of providing retail refuelling and charging infrastructure for hydrogen and battery electric vehicles, NREL found that 'levelized retail capital costs per mile are essentially indistinguishable given the uncertainty and variability around input assumptions.'[122]

Conclusions

It is clear that battery and plug-in hybrid electric vehicles have already made a head start over hydrogen fuel cell vehicles, primarily due to their lower cost and lower infrastructure requirements for an initial roll-out. For the foreseeable future at least, BEVs and PHEVs are likely to dominate FCEVs within the car market, and to this end the Government should continue to focus primarily on the roll-out of electric charging infrastructure.

However, it will be far more difficult for battery electric vehicle technology to make headway in respect of larger vehicles such as HGVs and buses, due to the size and weight of batteries that would be required. Hydrogen fuel cells have the advantage of a much higher energy density than lithium-ion batteries, which means that they are more suitable for larger vehicles with high mileage, especially HGVs. Nikola Motor Company, for example, is developing a hydrogen-powered HGV that they claim could travel up to 1,200 miles without refuelling.[123] Battery powered HGVs are being developed, but they cannot compete with FCEVs for range and speed of refuelling - two key features required for the long distance haulage industry. BMW's 40 tonne battery powered truck has a range of just 62 miles and requires 4 hours to fully charge.[124] BMW plan to use these trucks only for transporting equipment over short distances in an urban environment.

This means that the optimal path for the decarbonisation of road transport may require battery electric and hydrogen vehicles to be deployed in parallel – as complementary technologies for different types of vehicles. This seems to be the Government's approach, as the DfT's recent Low Emissions Freight competition allocated funding predominantly for electric light vans and hydrogen-fuelled HGVs.[125] The Government should continue this cautious approach to hydrogen, whilst also directing research funds towards developing cleaner and more efficient forms of hydrogen production.

Recommendation:

- **Government funding for the deployment of hydrogen vehicles and infrastructure should continue to focus on heavy duty vehicles (HGVs, buses) as this appears to be the vehicle segment where hydrogen has a potential advantage over BEVs.**

Biofuels

Biofuels are those produced from renewable biomass and they can be mixed with or substituted for fossil fuels. Liquid biofuels like ethanol and biodiesel are generally used as substitutes for petrol and conventional diesel, whereas the most common gaseous biofuel is biomethane, which is chemically similar to natural gas and can be employed as a direct substitute in the same applications.

First generation biofuels used food crops as feedstock to produce bioethanol (e.g. from corn, wheat and sugar cane) and biodiesel (e.g. from rapeseed, palm

122 NREL (2014) *Retail Infrastructure Costs Comparison for Hydrogen and Electricity for Light-Duty Vehicles*

123 Ars Technica UK (2016) 'Nikola reveals hydrogen fuel cell truck with range of 1,200 miles'

124 Wired (2015) 'BMW's 40-tonne electric truck hits public roads'

125 DfT/OLEV/Inovate UK (2017) 'Low emission freight and logistics trial competition winners announced'

or soybean oil, tallow and used cooking oil). They have fallen out of favour in many parts of the world due to a growing recognition of the downsides. The displacement of food crops has the potential to raise food prices, whilst the increased demand for food crops may result in land use changes which increase carbon emissions.

Second generation biofuels sought to address these sustainability issues by using non-food crops such as wood, organic waste, food crop waste and specific biomass crops, or through the anaerobic digestion of municipal waste or manure. They include biogas (or biomethane) produced from the anaerobic digestion of organic matter, such as sewage or food waste, and can also be made through the gasification of residual waste (as discussed in our report *Going Round In Circles*[126]).

Advanced, or third generation biofuels, are novel technologies that are still in the R&D or pilot stage, such as producing fuels from algae. Advanced biofuels offer the potential for orders of magnitude increases in production whilst significantly reducing land requirements and the possibility of adverse side-effects such as deforestation or food crop displacement compared with first generation biofuels. The future holds the promise of more advanced production techniques which use alternative feedstock and incorporate complex processes, enzymes and even micro-organisms. However, these are unlikely to be commercially viable in the short-to-medium term, hence this section primarily considers contemporary biofuel production processes.

The use of biofuels has been encouraged via policy commitments at both UK and European level. The Renewable Energy Directive (RED) requires EU member states to meet 10% of transport energy from renewable sources by 2020, while the Fuel Quality Directive (FQD) requires that member states reduce the emissions intensity of transport fuels by at least 6% by 2020. Both require that biofuels offer emissions reductions of at least 35% compared with conventional fossil fuels, increasing to 50% from 2017 and 60% from 2018. If supplied entirely from biofuels, the RED target will equate to roughly a 14% ethanol mix and an 11% biodiesel mix.[127] The RED and FQD were amended by Directive 2015/1513 which introduced the following changes:

- A cap of 7% in 2020 for the contribution of 'crop biofuels'
- Consideration of land use change
- National targets for fuels and feedstocks previously defined as 'advanced biofuels'
- An additional category of 'advanced fuel' for renewable liquid and gaseous transport fuels of non-biological origin[128]

The UK policy lever for realising these targets is the Renewable Fuel Transport Obligation (RFTO), which introduced a system of Renewable Fuel Transport Certificates (RTFCs). The UK introduced the RTFO in November 2005 as its primary mechanism for delivering the RED and FQD. It obliges major fossil fuels suppliers (over 450,000 litres of petroleum per annum) to certify that a specified percentage of the road fuels they supply are renewable fuels. RTFO obligations are satisfied by the purchase and generation of Renewable Transport Fuel Certificates.

126 Howard, R. et al (2017) *Going Round in Circles.*, Policy Exchange

127 Bailey, R. (2013) *The Trouble with Biofuels: Costs and Consequences of Expanding Biofuel Use in the United Kingdom*, Chatham House

128 European Commission (2015) *Directive 2015/13*

Targets under the RTFO required these major suppliers to bring the biofuels content of their transport fuel to 4% in 2011/12, increasing to 5% from 2013. In 2015/16, the renewable content of UK road transport fuels stood at less than 3%, although it is unclear whether double-counting of fuels derived from some waste products enabled the UK to meet its targets. It is now possible to find mixes of 10% (E10) for ethanol and 7% (B5) for biodiesel under UK fuel standards, although higher mixes have been supplied and used successfully.[129] Raising the biofuel fraction of transport fuel remains one option for fulfilling the UK's RED transport targets, although this has become less popular in recent years. Given Brexit, the difficulty presented by the RED targets, and the sustainability concerns surrounding biofuels usage, it seems that biofuels are unlikely to play a major role in the decarbonisation of road transport without the advent of more advanced production methods. For these reasons, the Government's proposed amendments to the RTFO focus upon maximising fuels derived from waste while providing for the introduction of renewable hydrogen.[130]

Emissions reduction

The decarbonisation potential of biofuels is a subject of significant debate. On face value they provide a 'sustainable' solution – the most direct route to turn sunlight into a usable transport fuel. The burning of crop-based fuels simply releases the carbon that was removed from the atmosphere when the crops were grown, resulting in a zero net effect on emissions. However, over the complete life-cycle of the product this is not necessarily the case. Biomass is not a dense store of energy; the costs of transporting and storing it are sizeable, both in financial terms and more significantly in terms of carbon emissions.[131] Still more important are the effects of land-use-change, as increased demand for biofuels leads to an increased demand for agricultural land, which in turn can lead to deforestation and the displacement of crops and farming methods that have more sustainable carbon profiles than intensively-farmed, high-yield varieties used to create biofuels.[132]

Increasing awareness of this phenomenon, through a series of research reports,[133] has meant that Defra now publishes side-by-side estimates of CO_2 emissions avoided via biofuels that both include and exclude land use concerns.[134] The EU has followed suit in Directive 2015/13 which limits the use of crop-based biofuels, and mandates a focus upon emissions associated with land use change.[135]

Meanwhile, the air-miles of UK biofuels have reduced dramatically. Whereas the majority of UK ethanol used to come from Brazilian sugar cane, transitioning around 2010 to US corn and then European cereals, the UK now produces the largest proportion of its ethanol from domestic wheat (24%).[136] This contribution is followed in size by imports from the UK's closest European neighbours.[137] By on-shoring an increasing proportion of its biofuels supply, the UK has significantly reduced air miles, and is gradually negating emissions associated with land use change (see the diminishing gap between the two columns in Figure 2.9).

129 DfT (2017) *Freight Carbon Review 2017*

130 DfT (2016) *The Renewable Transport Fuel Obligations Order: Proposed amendments*

131 Yergin, D (2011) *The Quest: Energy, Security and the Remaking of the Modern World*

132 Commonly referred to as land use, land-use change and forestry via the acronym 'LULUCF'

133 AEA Technology (2008) *Review of work on the environmental sustainability of international biofuels production and use.*, Defra

134 See published Defra biofuel reports: Defra (2017) *Biofuels Statistics Collection*

135 European Commission (2015) *Directive 2015/13*

136 DfT (2017) *Biofuel statistics: Year 9 (2016-17), report 2*

137 DfT (2016) *Biofuel statistics: Year 8 (2015-16), report 6*

Figure 2.8: Sources of for UK biofuels by country (2015-16)[138]

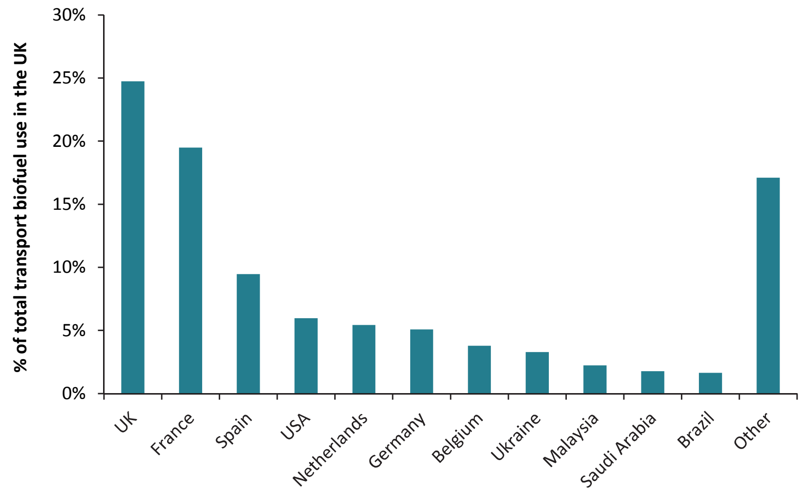
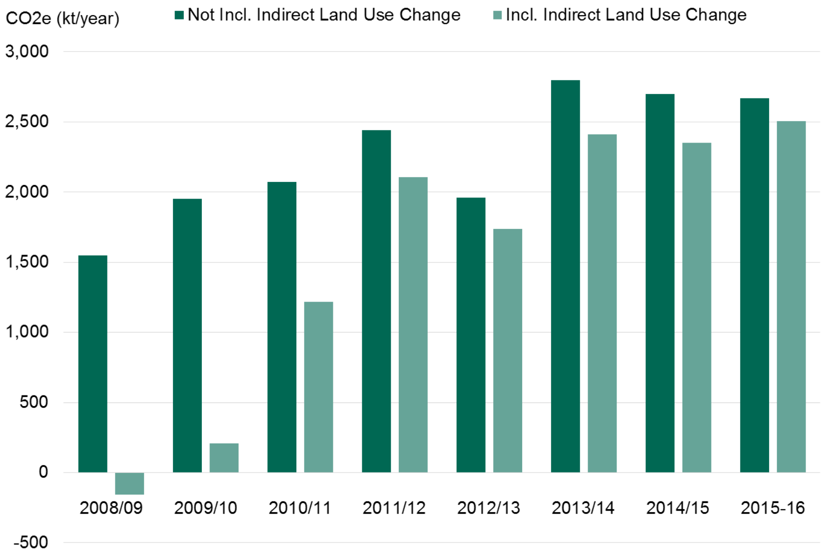


Figure 2.9: Greenhouse gas saving delivered by biofuel supplied to the UK[139]



However, it is thought that much of the 'low-hanging fruit' has now been picked. Further increases in the use of biofuels in the UK could begin to erode the emissions savings from biofuel use. Vehicles running on 100% Used Cooking Oil have shown emissions reductions of up to 84% (well-to-wheel emissions) in the Low Carbon Truck Test, but other liquid biofuels do not fare nearly so well.[140] It is thought that the UK could plausibly produce 210 million litres derived from used oils each year.[141] This would represent a significant increase on present production levels but it is dwarfed by the required increase in biofuels usage to meet the RED

138 Ibid.

139 Ibid.

140 Atkins/Cenex (2016) *Low Carbon truck and Refuelling Infrastructure Demonstration Trial Evaluation: Final Report to the DfT.* Sustainable Transport Solutions ltd (2008) Life Cycle Analysis of Road Transport Biofuels

141 Bailey, R. (2013) *The Trouble with Biofuels: Costs and Consequences of Expanding Biofuel Use in the United Kingdom*, Chatham House

obligations.[142] Domestic tallow faces similar limits, with a ceiling of around 240-260 million litres per annum.[143] Although these options would be preferable to conventional fuels from an emissions perspective, it is unlikely that they would be sufficient to achieve the European biofuel targets. It appears that without significant technological innovation, a rapid increase in biofuels use would require a substantial increase in the demand for fuel crops, along with associated greenhouse emissions.

Through a series of policy changes, the UK has successfully managed to increase biofuel production and usage whilst minimising impacts on land use change, principally by focusing on biofuels derived from wastes rather than from energy crops. The UK now produces more than 70% of total renewable transport fuel from waste products as opposed to energy crops. Using waste to create biofuels in this way has significant merit (the materials could otherwise end up in landfill) but there is a limit to the available supply of waste feedstocks. Given the constraints on the supply of existing sustainable biofuels, this makes them unlikely to be a long term solution. At best they represent an interim and limited answer to the problem of decarbonisation, and quite an expensive one. Where other technologies have vastly superior emissions characteristics, it begs the question as to why policymakers should not opt directly for a long-term solution such as ultra-low emission vehicles.

On air quality grounds there appears to be little benefit from the use of biofuels in place of conventional fuels. Although ethanol blends show reductions in most exhaust pollutants, they result in significant emissions of acetaldehyde - both a carcinogen and an ozone precursor. A 2008 report also noted that where action was not taken to reduce the volatility of low volume (0 to 10%) bioethanol blends, then they may show substantially greater evaporative emissions.[144] Evaporative emissions decrease from this point, and at 85% are actually less than for conventional fuels. For biodiesel, the commonly held perception is that there is a fairly sizeable reduction in most pollutants, but a possible slight increase in NO_x emissions.[145] The key question is whether such a limited improvement is enough to justify an expansion in biofuel use.

Consumer cost/impact

From a consumer point of view, it is important to consider both the cost and convenience of targeting an increase in biofuel usage.

Biofuels can be blended into conventional fuels up to a threshold of 15% with minimal impact on consumer convenience. Below this threshold, existing engines are capable of using blended fuels as a drop-in replacement. However, the use of pure biofuels, or blends above the 15% threshold is more problematic as most existing engines in the UK would be unable to tolerate the amount of biofuel.[146] It has been suggested in government research that without warranties from vehicle manufacturers and suitable economic incentives throughout the supply chain 'there is no confidence within the haulage and public service sector, or the private sector to move towards higher biofuel blends.'[147] More flexible engines could be incorporated into new vehicles, allowing higher ratios of biofuels to be signalled and introduced over time. There are many markets around the world in which flexible fuel vehicles are commonplace. This is by no means new technology - mixed fuel vehicles that run on either petrol or ethanol go as far back as Henry Ford's Model T in the early 1900s.[148] However, in order to drive a move to flex-fuel vehicles, the UK would have to make a significant commitment to move to biofuels, which given the sustainable concerns raised above, seems unlikely.

142 DfT (2016) *Biofuel statistics: Year 8 (2015-16), report 6 (data)*

143 Bailey, R. (2013) *The Trouble with Biofuels: Costs and Consequences of Expanding Biofuel Use in the United Kingdom*. Chatham House

144 AEA Technology (2008) *Review of work on the environmental sustainability of international biofuels production and use.*, Defra

145 Sustainable Transport Solutions ltd (2008) *Life Cycle Analysis of Road Transport Biofuels*

146 Ibid.

147 AEA (2011) *Assessment of the existing UK infrastructure capacity and vehicle fleet capability for the use of biofuels*

148 Yergin, D (2011) *The Quest: Energy, Security and the Remaking of the Modern World*

Biofuels are also a more expensive option than conventional liquid fuels. A 2012 study found that increasing biofuel use to 10% by 2020 (in line with the European RED target) would cost an additional £1-2 billion per annum. This would add 2-4 pence per litre to the cost of all liquid fuels used in the UK *across all consumers*.[149]

Significantly increasing biofuel usage based on energy crops could result in a knock-on effect on food prices for consumers – since some energy crops are also used for food. As the US corn ethanol industry has grown, the price of staple foods south of the border in Mexico has been affected.[150] A rapid increase in EU biofuel production would increase demand for cereals, which may have an impact on cereal prices (in Europe and elsewhere). This may raise questions in terms of welfare in the developing world, for example if food prices are being driven up by demand for biofuel inputs.

Infrastructure cost/impact

Switching to biofuels requires investment upstream in biofuel production and refining as well as investment downstream in refuelling stations – some of which is already in place. Biodiesel and bioethanol blends are already available at many fuel stations across the UK. Rolling out pure biofuels would require some additional investment in additional pumps and storage tanks. According to a DfT survey, 'installation of additional tank space is costly and logistically difficult at most sites.'[151] Nonetheless, the scale of investment required is minor compared to other pathways for road transport such as the infrastructure required for ULEVs. For the consumer there would be almost no change in behaviour required, and adoption of biofuels would be even easier for fleet vehicles and haulage firms.

Greater change would be visible further upstream, in terms of biofuel production and refining. As noted above, the cost of achieving the 20% renewable transport fuel target would be £1-2 billion per annum in 2020 including the cost of this additional infrastructure (albeit that this estimate largely does not account for rising land prices and the movement of global prices for agricultural produce and conventional fuels).[152]

Conclusions

Overall, our view is that biofuels are likely to make a limited contribution towards the decarbonisation of road transport in the UK. They could potentially play a role in the decarbonisation of large vehicles such as HGVs and buses, where there are few options available, but do not present a sufficiently scalable solution for the decarbonisation of the much larger car and van fleet. The air quality impacts of biofuel use are mixed at best.

Recommendations:

- **Following Brexit, the UK should re-examine its policies regarding biofuels.** The principal focus should remain on waste-derived biofuels rather than biofuels derived from energy crops.
- **The UK should abandon the arbitrary European target of 10% renewable transport fuel by 2020 (which it is unlikely to achieve in any case).** In general, the UK should avoid setting technology specific targets of this nature and instead focus on managing environmental outcomes such as the total greenhouse gas and NO_x emissions from road transport.

149 Charles, C. & Wooders, P. (2012) *Biofuels – At What Cost? Mandating ethanol and biodiesel consumption in the United Kingdom*. International Institute for Sustainable Development

150 BBC (2007) *Mexicans stage tortilla protest*

151 AEA (2011) *Assessment of the existing UK infrastructure capacity and vehicle fleet capability for the use of biofuels*

152 Charles, C. & Wooders, P. (2012) *Biofuels – At What Cost? Mandating ethanol and biodiesel consumption in the United Kingdom*, International Institute for Sustainable Development

Natural Gas

This section considers the potential for the use of alternative fuels derived from natural gas, which include:

- **Liquefied Petroleum Gas (LPG, also referred to as Autogas)** consists of a mixture of propane, propylene, butane and butylene and is commonly obtained as a by-product of natural gas processing and petroleum refining.[153] Because the gas mixture is liquid when stored under moderate pressure, it is fairly easy to handle. It is primarily used for domestic heating, but a small number of motorists in the UK have begun to use LPG as a transport fuel since it was made available on UK forecourts since the mid-1990s. DfT statistics suggest there are just 40,000 LPG cars on the road, and fewer than 10,000 LPG powered vans.[154] However, these numbers only count registered vehicles, and other estimates that include unregistered LPG conversions of existing vehicles put the total number of gas powered vehicles on UK roads at around 200,000.[155] Many of these conversions are bi-fuel, meaning they can run on LPG or petrol/diesel. LPG is used widely across Europe, with 10 million LPG vehicles on the road and 37,500 filling stations.[156]
- **Compressed Natural Gas (CNG) and Liquefied Natural Gas (LNG)** refer to ways of storing natural gas for use in transport. The former involves storing it at very high pressure (between 200 and 250 bar) while the latter is methane that has been cooled to between - 120 and -170°C, at which point it becomes a liquid.[157] There are very few CNG and LNG vehicles on UK roads at present, but interest is growing. One estimate suggested that there were just 559 CNG vehicles on the road in 2016.[158] They are much more common in certain other countries, notably America, where various tax incentives and low natural gas prices have resulted in around 23% of transit buses now running on natural gas.[159]

The Government has recently begun to explore the potential benefits of these fuels for transport, primarily via the Low Carbon Truck and Refuelling Infrastructure Demonstration Trial.[160] They are also featured prominently in the Government's Freight Carbon Review 2017 and in the proposed revisions to the Renewable Transport Fuels Obligations.[161]

Emissions reduction

Based on tailpipe emissions of carbon dioxide alone, both LNG and CNG vehicles emit slightly less than a similar sized diesel or petrol vehicle. This is because these fuels contain a lower fraction of carbon and so less CO_2 is produced in the combustion process (see Figure 2.10). However, the total lifecycle greenhouse gas emissions are more uncertain due to the issue of methane leakage (particularly for CNG). Methane is a very potent greenhouse gas, so even small amounts of leakage in production and transportation can amount to a high greenhouse effect when measured in carbon dioxide equivalent (CO_2e). Methane slip, unburned methane emitted through the exhaust, can also be significant.

153 Environmental Protection Agency: 'Air Emissions Factors and Quantification'

154 DfT (2013) 'Car statistics tables, produced by Department for Transport'

155 www.moneysupermarket.com (2012) 'Could LPG save you a fortune?'

156 Howard, R. (2016) *Up in the Air: How to solve London's air quality crisis - Part 2*, Policy Exchange

157 Alternative Fuel System Inc (2007) 'What's the difference between CNG, LNG, LPG and Hydrogen?'

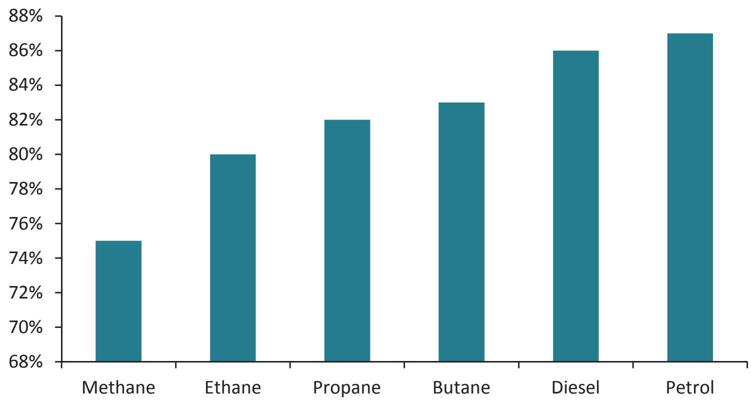
158 NGV Global (2017) 'Current Natural Gas Vehicle Statistics'

159 Alternative Fuels Data Centre (2017) 'Maps and Data - U.S. Transit Buses by Fuel Type'

160 Atkins and Cenex (2016) *Low Carbon Truck and Refuelling Infrastructure Demonstration Trial Evaluation*, Department for Transport

161 DfT (2017) *Freight Carbon Review 2017*

Figure 2.10: Carbon fraction of fuels used for transport[162]



A study by the Low Carbon Vehicle Partnership[163] (LowCVP) aimed to measure reductions in carbon dioxide emissions and pollutants by switching from diesel to CNG or LPG. They compared a dedicated Euro VI Natural Gas HGV and a number of HGVs converted to natural gas against an equivalent sized diesel HGV. They found that the dedicated natural gas vehicle could, at best, reduce tailpipe emissions by 5% (compared to an equivalent diesel HGV) whilst the diesel-LPG dual-fuel conversion achieved similar modest reductions in CO_2 emissions. However, because of methane-slip, the duel-fuel diesel-natural gas conversion was found to actually increase overall greenhouse gas emissions by 20%. In another study, Argonne National Laboratory attempted to quantify the life cycle emissions savings from switching to LPG and CNG and found that they achieved 6-11% life cycle savings compared to gasoline vehicles.[164]

Whilst the savings in terms of greenhouse gas emissions are relatively low and uncertain, natural gas vehicles do offer significant benefits in terms of reducing emissions of NO_x and PM, particularly if replacing older diesel vehicles.

A study by Defra found that a van converted to run on LPG had NO_x emissions 80% lower than a Euro VI standard diesel van (Table 2.3). Regarding CNG, the same report says that a buses running on biomethane will emit between 84% and 89% less NO_x compared to a conventional Euro IV bus at a speed range between 15 and 30 mph. Test results for a Euro 4 London taxi converted to run on LPG show an 80% reduction in NO_x emissions and 99% reduction in PM emissions, and 7% reduction in CO_2 emissions compared to a diesel equivalent.[165]

162 Bielaczyc, P. et al (2016) 'A comparison of exhaust emissions from vehicles fuelled with petrol, LPG and CNG', *Materials Science and Engineering* 148

163 DfT (2017) 'Emissions testing of gas-powered commercial vehicles'

164 Alternative Fuels Data Centre (2017) 'Natural Gas Vehicle Emissions'

165 Calor (2017) 'Converting London Black Cabs to LPG Autogas will deliver air quality benefits well saving cabbies money'

Table 2.3: LPG van NO_x emissions relative to equivalent diesel van[166]

Year	Urban	Rural	Motorway	Relative to...
1994-1996	0.56	0.45	0.44	Euro 1 diesel van
1997-2000	0.19	0.16	0.15	Euro 2 diesel van
2001-2005	0.11	0.10	0.09	Euro 3 diesel van
2006-2010	0.09	0.07	0.06	Euro 4 diesel van
2011-2015	0.09	0.07	0.06	Euro 5 diesel van
2016-	0.20	0.16	0.14	Euro 6 diesel van

Atlantic Consulting[167] assessed the impact on air quality of introducing 40,000 LPG vehicles to UK roads every year from 2016 to 2029.The analysis found that significant reductions in NO_x could be achieved, regardless of whether the LPG vehicles displaced old diesels, new diesels, or petrol vehicles. Atlantic also conclude that emissions reductions achieved through LPG substitution are more cost effective than achieving the same reductions by other means (based on Defra data cited in the report).

Although most studies agree that both LNG and CNG fuelled vehicles emit much less NO_x and PM than similar sized diesel models, the exact benefits are difficult to quantify for a number of reasons:

- Different types of driving will affect emissions (urban versus rural versus motorway driving).
- The specification and quality of the gaseous-fuelled vehicle drivetrain will vary and so too will emissions.
- Real world emissions of diesel vehicles have not been adequately quantified.
- The benefit of switching depends on the 'dirtiness' of the vehicle being displaced. For example, analysis by TfL[168] found that new Euro VI HGVs have much reduced NO_x emissions compared with their predecessors (up to 98%), so the benefits of switching from a recent diesel vehicle to a natural gas vehicle are less pronounced than substituting gas for older vehicles.

Cost / consumer convenience

Switching to natural gas fuels is already a financially attractive option for motorists. The cost per litre of LPG is, at the time of writing, approximately half that of diesel.[169] This is in part due to the fact that the fuel duty levied on LPG (31 pence per kg, or 16 pence per litre) is much lower than that on petrol or diesel (58 pence per litre). Diesel cars can be converted to run on LPG for around £1200[170], with this investment offering a return within 20,000-30,000 miles.

Dedicated natural gas vehicles typically cost more than petrol or diesel vehicles due to the extra fuel storage requirements and engine modifications[171], but this disparity could close with more widespread deployment due to economies of scale.

166 NAEI (2013) *Emission Factors for Alternative Vehicle Technologies*

167 Atlantic Consulting (2015) *UK air-emissions impact of introducing 40,000 LPG cars per year during 2016-2029*

168 TfL (2015) *In-service emissions performance of Euro 6/VI vehicles: A summary of testing using London drive cycles*

169 www.petrolprices.com

170 Drive LPG (2017) 'How much will it cost to convert'

171 US Department of Energy (2007) *Natural Gas as a Transportation Fuel Benefits, Challenges, and Implementation*, NREL/PR-540-41884

The LowCVP analysed the ownership cost a CNG van with its nearest diesel equivalent and of converting a diesel van to run on LPG. Although the CNG Mercedes Sprint 316 costs £3k more than the diesel model, lower fuel prices result in the six year ownership costs being £1,823 lower. The LowCVP quote the cost of converting petrol Vauxhall Combo 1.4i to LPG as £1,200, but again, due to fuel price savings, the five year ownership costs are lower, this time by £1,387.

For the owner, the process of refuelling with LPG is virtually the same as with petrol and diesel, whilst there are a number of different refuelling options for CNG. Fast fill stations can refuel a CNG vehicle in approximately the same time as diesel vehicle, whilst fleet operators may instead use time-fill which will fill up the tank more slowly overnight.[172]

Infrastructure

LPG refuelling infrastructure is largely in place already so this would not constitute a barrier to more wide-scale take-up. There are already over 1,400 LPG filling stations around the country, which are usually located at conventional petrol stations.[173] However, as LPG is commonly produced as a bi-product of crude oil refining, it is not clear whether orders of magnitude increases in production could be achieved economically if standalone LPG production facilities were to be required. However, global production has increased substantially in recent years, owing mostly to the American shale gas revolution, so lack of supply is not an imminent concern.[174]

CNG refuelling facilities are less widespread (12 in total comprising five private stations and seven with public access across Britain[175]) due to the lower number of vehicles on the road, but it would not be a major undertaking to add additional stations in parallel to a more widespread deployment of CNG vehicles. Businesses could also quite easily set up their own dedicated refuelling facility to serve their fleet, as many bus companies already do in America.[176]

Conclusions

Our assessment is that switching from conventional fuels to natural gas offers little in the way of greenhouse gas savings (once methane slip is taken into account) but does offer significant potential to reduce local pollution (particularly compared to diesel). There has been a limited uptake of LPG cars in the UK, principally through aftermarket conversions, predicated on fuel savings alone. This should not be discouraged, but is unlikely to have a significant impact on overall road transport emissions. Where there is more potential is as an alternative fuel for larger vehicle types (vans, HGVs, buses) which currently run almost exclusively on diesel. Larger vehicles are unlikely to switch to ultra-low emission technologies just yet, due to the additional costs involved (see previous section) hence natural gas could be an attractive option, particularly in the short to medium term, as a way to tackle air pollution in urban areas.

Recommendations:

- **Local Authorities should consider replacing older diesel buses with new models that run on CNG.**
- **Expand incentives offered to taxi operators under the Clean Vehicle Technology Fund to convert diesel taxis to run on LPG. We commend the introduction of this scheme, as recommended in our previous report *Up in the Air*.**

172 US Department of Energy (2015) *Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure*

173 Drive LPG (2017) 'Where can I purchase fuel'

174 ICF International (2016) *2016 Propane Market Outlook*

175 Gas Vehicle Hub (2014) 'Refuelling Facilities'

176 US Department of Energy (2007) *Natural Gas as a Transportation Fuel Benefits, Challenges, and Implementation*, NREL/PR-540-41884

- **HM Treasury should provide greater certainty for motorists about fuel duty on LPG and other gaseous fuels.** At present the level of fuel duty on LPG and other gaseous fuels is low relative to petrol and diesel. However, the differential has reduced since 2001, creating uncertainty for motorists about whether switching to LPG will represent long term value for money. HM Treasury should commit to maintaining the current differential between fuel duty on LPG versus petrol/diesel for a period of 5-10 years.

Modal Shift and Behaviour Change

This section looks at the contribution that modal shift and behaviour change can make in reducing road transport emissions. Modal shift involves substituting the transportation of goods and people from one mode of transport to another, whilst in this context we take behaviour change to mean changing the way a form transport is used in order to reduce transport emissions. Opportunities to reduce emissions through modal shift and behaviour change include:

- Modal shift
  - Transporting freight by rail instead of road
  - Shifting personal transport from cars to public transport or cycling/walking
- Behaviour change
  - 'Mobility as a service' models including car sharing
  - Connected and autonomous vehicles

Rail freight

There is a significant opportunity to reduce transport emissions by shifting freight from road vehicles to rail. In total, road freight (Heavy Goods Vehicles and light vans) was responsible for one third of total greenhouse gas emissions from transport in 2015.[177] By contrast, the total greenhouse gas emissions from rail (including both freight and passengers combined) are an order of magnitude lower at less than 2% of total UK transport emissions. Each tonne of freight transported by rail reduces carbon emissions by 76% compared to road, and each freight train removes 43 to 76 HGVs from the roads.[178] According to the Rail Freight Group[179] compared with carrying the same tonnage by road, rail produces less than one tenth of the carbon monoxide, around one twentieth of the NO_x, less than 9% of fine Particulate Matter, and around 10% of the emissions of Volatile Organic Compounds.

In a study considering the carbon emissions associated with transporting a tin of beans, it was found that rail freight produces one third of the CO_2 emissions of transport the same goods by road.[180] A tonne of goods can travel 246 miles by rail on a gallon of diesel, compared to only 88 miles by road.[181] Therefore, it is easy to see that shifting more freight from road to rail has the potential to contribute to reducing both greenhouse gas emissions and local pollution.

Rail freight is an important, albeit minor, part of the freight market and rail market. Freight trains currently make up about 10% of all trains operating on the UK rail network.[182] The Office of Rail Regulation (ORR) identified that in 2014, 12% of all freight in Britain was moved by rail.[183] Table 2.4 identifies the main commodities moved by rail.

177 BEIS (2017) 'Final UK greenhouse gas emissions national statistics: 1990-2015'

178 DfT (2016) *Rail Freight Strategy: Britain Moving ahead*

179 www.rfg.org.uk/facts-and-statistics

180 Ibid.

181 Ibid.

182 www.rfg.org.uk/policy

183 ORR(2016) *ORR Freight Rail Usage 2015-16 Q4 Statistical Release*

Table 2.4: GB rail freight by commodity 2015-16[184]

Commodity	% share of rail freight market
Domestic Intermodal	36.2
Construction	22.4
Coal	13.1
Other	10.5
Metals	8.6
Oil and Petroleum	6.6
International	2.7

Since privatisation of the rail industry in 1993/4, there has been long term growth in the rail freight market. For example, between 1993 and 2012 there was a 40% increase in the volume of freight moved by rail.[185] There has also been investment in new rolling stock and equipment of over £2bn.[186] However, a number of recent developments in the rail freight market have led to a sharp fall in rail freight volumes in the last couple of years, with a reduction of 20% in 2015/16 alone.[187]

- Firstly, the amount of coal transported by rail is significantly decreasing, with a reduction of 64.2% in 2015-16 compared to 2014-15.[188] This is due to the ongoing decline in coal power generation, which will only continue as the UK has committed to phasing out coal altogether by 2025. As we documented in a previous report, *Power* 2.0, some 19 GW of coal power stations have already closed since 2010, and a further remaining 14 GW is to be phased out by 2025.[189] Coal traffic on the rail network could effectively end altogether in eight years' time.[190]
- Secondly, global events in the steel market, and the knock on impact on the UK steel industry, have resulted in a 15.7% drop in the amount of metal moved by rail in 2015-16 (compared to 2014-15).[191]
- Thirdly, the whole freight sector is evolving with the changing patterns of consumption caused by the rise of internet shopping and next-day deliveries. This means that the whole UK freight market is moving away from the types of freight that the railways have traditionally focused on.
- Lastly, the migrant crisis at Calais has been a factor in the 20.5% reduction on international traffic from 2014-15 to 2015-16.[192]

These are significant changes for the rail freight sector that will see a loss of revenue, a surplus of rolling stock and significant spare capacity on the network. This presents a significant opportunity to move other types of freight from road to rail – although to achieve this, rail freight will need to move away from traditional sectors such as coal and steel, to new markets.

The rail industry and the Government have been actively looking at the scale of the opportunity to move road freight to rail. In 2016, DfT commissioned Arup to assess rail freight growth potential by commodity sector, including reviewing

184 Ibid.

185 Freight on Rail (2017) 'Facts and Figures at a Glance'

186 Ibid.

187 International Rail Journal (2016) 'Brexit, coal collapse and capacity issues add to British rail freight woes'

188 ORR(2016) *ORR Freight Rail Usage 2015-16 Q4 Statistical Release*

189 Howard, R. and Bengherbi, B. (2016) *Power 2.0.*, Policy Exchange

190 BEIS (2016) 'Coal generation in Great Britain: The pathway to a low-carbon future'

191 ORR(2016) *ORR Freight Rail Usage 2015-16 Q4 Statistical Release*

192 ORR (2016) *ORR Freight Rail Usage 2015-16 Q4 Statistical Release*

any capacity constraints that could limit this modal shift. The report, *Future Potential for Modal Shift in the UK Rail Freight Market*, identified four commodity sectors as having potential for rail freight growth: construction materials, intermodal freight, Channel Tunnel, and automotive sectors.[193] It also identified ten illustrative measures which combined could lead to emissions savings of around 2.3 $MtCO_2e$ (the total GHG emissions from HGVs are 20$MtCO_2e$).

The two most significant interventions, upgrading rail network capacity and making more efficient use of existing capacity, would account for over half of these savings. This shows that modal shift could make an important contribution to decarbonising freight.

There are a number of barriers to achieving this including:

- **Network Capacity:** The size and shape of the rail network is designed around current use patterns with very little spare capacity. The decline in coal movements will open up spare capacity, but most likely in the wrong places. Increasing rail freight flows may not be possible without capital expenditure on additional track, terminals and rolling stock. Network congestion is already an issue for both freight and passenger operators, and there would be resistance form current operators to new freight flows adding to this.
- **Flexibility:** The ability of the rail network to offer the service that the Freight Operating Companies (FOCs) and its customers are looking for may also be limited. The timetabling arrangements to fit freight trains into a busy network means that rail freight is not as flexible as road freight. There are challenges in offering timetable changes at short notice to meet customer requirements, and network maintenance constraints means the railway is unable to offer the same 24/7 service that is available on the road network. For the FOCs there is an optimal operational level, with full trains, of the same length with the same loads, operating a timetable that maximises rolling stock utilisation. The number of customers who require this is limited which restricts the opportunity for new flows to be transferred to rail. In addition, the capital cost of building new wagons and sidings means that FOCs can only get their money back if they know the traffic will last for a number of years.

Recommendations:

- **Government and the rail industry should identify pinch points on the rail network that constrict freight movement and develop a strategy to resolve them.**
- **Network Rail and the FOCs should review utilisation of the network to identify when it is not busy with passenger trains, as a way of freeing up capacity for more freight trains to run.**

Further carbon savings could be made by the haulage of freight trains by electric locomotives rather than diesel. Around 40% of the GB rail network is electrified.[194] However, only 7% of freight is hauled by an electric locomotive, despite the better traction performance that electric locomotives offer.[195] The current Freight Operating Companies (FOCs) have preferred the flexibility of diesel locomotives which can go anywhere on the network. Rail electrification in the UK has mainly focused on

193 Arup (2016) *Future potential for modal shift in the UK rail freight market*

194 Arup (2016) *Future potential for modal shift in the UK rail freight market*

195 Ibid.

passenger flows meaning that marshalling yards, sidings and branch lines used predominantly by freight trains are often not electrified. The result is that even if large parts of the route is electrified, the FOCs will frequently operate a freight train by diesel only to avoid the additional costs of swapping between diesel and electric locomotives. This has led to the underutilisation of GB electric locomotive fleet. For example, around half of the most modern UK electric freight locomotives (known as Class 92's) are in storage, and about a third of them have been moved abroad to pull freight trains in Romania and Bulgaria by owners DB Cargo.[196]

Increasing the use of electric locomotives for freight trains would require significant investment from Network Rail into the rail infrastructure. There are isolated examples of this happening. Network Rail are currently electrifying the north London orbital route between Gospel Oak and Barking. Meanwhile, FOCs are showing interest in hybrid diesel/electric locomotives that can switch between the two forms of power as required.[197] It can be costly to electrify a railway line. For example, the project to electrify the railway line between London and Cardiff is currently estimated to be around £2.8 billion.[198] However, with some smaller, more modest investments, freight trains could make better use of the part of the rail network which is already electrified.

Recommendations:

- **Government and the rail industry should agree on a short term targeted programme of works to encourage the use of electric locomotives.** For example, electrification of the 12½ mile branch line from Ipswich to Felixstowe would allow electrically hauled trains to operate directly between the UK's busiest container port at Felixstowe, and the UK's largest cities including London, Birmingham, Manchester Glasgow, Leeds, Liverpool and Newcastle.
- **The relative emissions of different types of trains should be factored into Network Access Chargers.** Electric trains which have lower carbon emissions should be charged less than diesel locomotives.
- **Government and the rail industry should agree an action plan to support the introduction of the new generation of hybrid diesel/electric locomotives that are currently being introduced to maximise their utilisation.**

Public transport and cycling

There is significant potential to shift passengers from private car use to more sustainable forms of transport such as public transport and cycling/walking, which can reduce road transport emissions and congestion, and has obvious health benefits. This is particularly so in urban areas where journeys are often short, car use has single/low occupancy, and journeys often happen in peak hours. Urban car commutes are particularly bad from a congestion and pollution point of view.

Moving people from cars to buses has a much greater impact on transport emissions than upgrading buses to be ultra-low emission, as analysis by the World Bank shows.[199] If a passenger commute by car emits 8kg of CO_2, the same commute by bus would emit 1.5kg. Switching the bus from diesel to hybrid diesel would only reduce the per passenger emissions to around 1kg, and even switching from diesel to zero emission buses has less of an impact per passenger than modal shift. For this reason, getting people to switch from cars to more sustainable forms

196 www.wnxx.com

197 Direct Rail Services (2016) 'Class 88 Locomotive'

198 *The Guardian* (2015) 'Cost of Great Western mainline electrification project triples to £2.8bn'

199 The World Bank (2017) 'Are hybrid and electric buses viable just yet?'

of transport (not just buses, but also trains and bicycles) could have a significant effect on emissions - much greater than technological change in some cases.

Modal shift is a complex and detailed topic, which extends far beyond the scope of this study. We have provided a brief summary of the potential benefits associated with greater use of buses, passenger rail and cycling.

Buses are the backbone of UK public transport system, with 60% of passenger journeys on public transport made by bus.[200] There were an estimated 5.04 billion bus passenger journeys made in Great Britain in 2016 (or an average of 77 journeys per person per year).[201] 91% of people in the UK are within a 13 minute walk of a bus stop with at least an hourly service.[202]

Bus use is diverging in London versus the rest of the country. Around half of all bus journeys in England were made in London[203] and bus passenger journeys have broadly doubled in the period 1985/86 to 2014/15.[204] However, outside London there has been a long term decline in the number of bus journeys from over 4 billion to just under 3 billion in the same period.[205]

There is a significant body of evidence that there is a direct correlation between improving the level and frequency of a bus service and an increase in usage. Use of the premium 'Vantage' routes in Manchester has grown from 28,000 to approaching 50,000 passengers a week in the first eight months of operation, leading to services being further increased.[206]

In addition, there seems to be a strong correlation between those areas of the UK where there is a strategic transport body which co-ordinates bus services, and an increase in bus ridership. For example, in Greater London, which has seen continued growth in bus use, TfL manages bus services via a tendering system, in which operators bid to operate routes.[207] The Government has acknowledged the benefits of a local strategic transport body overseeing bus route franchising, and included a number of measures in the Bus Services Act, which received Royal Assent in April 2017 (just before the General Election purdah period).[208] This includes powers for all local authorities to define standards for local bus services - including service frequencies, ticketing requirements, smart ticketing and discounts, - and to enforce these requirements through vehicle licensing. It also creates new powers for Metro Mayors to franchise bus services in their areas.

Recommendations:

- **Government should allow all local authorities (not just those with an elected Mayor) to take a leading role in the franchising of bus services.**
- **Government should take steps to ensure that franchising arrangements create a competitive market for bus services, rather than protecting incumbents** – in particular by ensuring that franchise arrangements do not create a barrier to smaller suppliers and those offering alternative business models.

With **Rail**, as with buses, there is a correlation between improved levels of service and an increase in passenger numbers. For example, passenger numbers have increased 60% on the East Suffolk Line since 2009/10 as the frequency of the service has increased.[209] Moreover, the electrification of rail services has a good track record of achieved modal shift, known as the 'sparks effect' within the rail

200 DfT (2017) *Rail Trends Factsheet*

201 DfT (2017) 'Bus Statistics'

202 Low CVP (2017) *Any Journey is Greener by Bus*

203 DfT (2016) *Transport Statistics Great Britain 2015*

204 Ibid.

205 DfT (2017) *Transport Statistics Great Britain 2016*

206 Low CVP (2017) *Any Journey is Greener by Bus*

207 TfL (2015) *London's Bus Contracting and Tendering Process*

208 DfT (2016) *The Bus Services Bill: An Overview*

209 Modern Railways (2014) 'Record numbers use East Suffolk Line'

industry. Newly electrified lines often show a significant jump in patronage. This is in part as electrification often goes hand in hand with new rolling stock and general infrastructure and timetable improvement.

About one third of the UK Rail Network is currently electrified.[210] The cost of electrifying a railway line means that this is concentrated on the busiest lines that include heavily used commuter routes into the UK's major cities. For example, when finished in 2018 the six-year North-West Electrification Project will see over 300km of track electrified between towns and cities including Manchester, Liverpool, Preston and Blackpool.[211] Not all of the busy commuter routes into our major cities are electrified. For example, none of the railway lines in cities such as Sheffield, Bristol, Nottingham or Belfast are electrified, and none of the 16 million passengers who arrive or depart from London Marylebone are on electric trains.[212] Currently, there are no plans to electrify many of these routes. Train Operating Companies are still purchasing diesel locomotives – locking themselves into this technology for a long time to come. For example, Northern Trains are planning to replace existing 'Pacer' diesel trains with new diesel trains which have a life expectancy of 30 years.[213]

Tram systems were in widespread operation across the whole of the UK prior to the Second World War. The combination of high renewal costs and low oil prices saw all areas except Blackpool abandon their tram systems in favour of buses in the post war period. Since the early 1990's there has been a revival of trams/light rail, with new schemes in cities including Manchester (1992), Sheffield (1994), Birmingham (1999), Croydon (2000), Nottingham (2004) and Edinburgh (2014). These followed the successful 1987 reintroduction of light rail in the London Docklands. Some UK cities, such as Bristol, Leeds and Liverpool have failed to develop a light rail network, despite quite advanced proposals. Those cities in the UK that have reintroduced Trams/Light Rail have seen considerable growth in passenger numbers. Around 2.7% of all public transport journeys in Great Britain are now made on light rail systems, with growth of 59% since 2005.[214]

As well as the development of new light rail networks, the UK is also considering new ideas such as 'train-tram' and ultra-light rail. Train-tram is a system where heavy rail services are linked together by new sections of light rail to provide new services. UK's first scheme is due for introduction in 2018, adding a new service between Rotherham and Sheffield to the South Yorkshire Supertram system. There are also some 'Ultra-Light rail concepts' in development. Currently, there is only one in operation on the Stourbridge Town Branch Line in the West Midlands. The Parry People Mover (PPM) uses a flywheel energy storage system for propulsion. It produces a third of the carbon dioxide emissions of the conventional diesel train it replaced, despite doubling the frequency of the service.[215]

Recommendations:

- **Accelerate the electrification of the network, such that by 2030 the 'core network' can be operated by electric trains.** For those lines where electrification is unviable, Government and the rail industry should investigate the feasibility of electric/diesel hybrids and battery powered trains.
- **Government should create a 'Rail Decarbonisation Innovation Fund'** to promote the development and deployment of low carbon trains. For example,

210 ORR (2017) 'Infrastructure on the railways - Table 2.52'

211 Network Rail (2017) 'North West electrification'

212 ORR (2017) 'Estimates of station usage'

213 Rail Technology Magazine (2016) 'Arriva signs £490m rolling stock contract to replace Northern's Pacers'

214 DfT (2016) 'Light rail and tram statistics'

215 Parry People Movers (2009) 'PPM Technology'

this could support a wide range of ideas from the trialling in the UK of Alstom's new emission free trains, further trials of battery technologies and new light rail or train-tram schemes.

- **Network Rail should undertake a study to identify further lines that are suitable for conversion to light rail**, train-tram and ultra-light rail, which could then be factored into future rail franchises.

More **bicycles** are sold in Great Britain than cars. Around 3.5 million were sold in 2015 compared to 2.6 million new cars registered in the same year.[216] Around 25 million people, or 42% of the population, own a bicycle in the UK.[217] Cycle traffic has risen almost every year since 2008, and around 4% of commuting trips in England are now done by bike and cycling trips collectively make up 0.8% of all road miles travelled.[218] 80% of cyclists also hold a driving licence, which means that they have a choice between car or bicycle journeys.[219]

Shifting people from cars to bikes could bring about significant savings in carbon emissions and air pollution. Switching a four mile each-way daily commute saves half a tonne of CO_2 emissions per year – or 6% of the average person's total carbon footprint.[220]

Whilst the potential savings from switching to cycling are great, only a handful of UK cities currently see significant numbers of people commuting by bike, including Cambridge (29%) and Oxford (17%).[221] Outside these cities (which have a significant student population) many other cities in the UK have seen an increase in cycling in recent years such as Sheffield (80% increase from 2001 to 2011), but from a very low base.[222] Overall, The UK still has amongst the lowest daily cycle rate in the EU at 4%, compared to Netherlands 43%, Denmark 30%, and Finland 28%.[223]

The evidence suggests that the creation of safe, segregated cycle lanes and priority measures at junctions tends to increase cycling levels in a city. The 243%[224] increase in cycling in London between 2001/02 and 2014/15 is in part due to TfL's programme of cycle superhighways to provide safer cycle routes into central London, and the introduction of a cycle hire scheme in 2010. There are now 750 docking stations in central London from which 11,500 bikes can be hired. In 2014, there were 10.1 million cycle hires.[225] However, across the UK there is a very mixed picture in terms of level of ambition, priority and investment from local bodies such as councils and Local Enterprise Partnerships in supporting the growth of cycling. For example, there are no national design standards for cycleways outside London[226] and Wales.[227]

The Government published its Cycling and Walking Investment Strategy (CWIS)[228] in April 2017, which details how they will allocate funding of £300m over period 2015-20.[229] But Sustrans' view is that to achieve the target of double cycling activity by 2025 would require investment of around £8.2 billion or £17 per person per year.[230] While this is a significant sum, Sustrans argues that this level of investment would result in an overall benefit cost ratio of nearly eight to one and would result in an estimated £61 billion of economic benefits from both cycling and walking.

216 Cycling UK (2016) 'Cycling UK's Cycling Statistics'; DfT Vehicle Statistics

217 Cycling UK (2016) 'Cycling UK's Cycling Statistics'

218 Ibid.

219 Ibid.

220 Cycling UK (2016) 'Climate Change'

221 ONS (2014) *2011 Census Analysis - Cycling to Work*

222 Ibid.

223 Cycling UK (2016) 'Cycling UK's Cycling Statistics'

224 TfL (2016) 'Cycling'

225 Ibid.

226 TfL (2017) 'Streets toolkit'

227 Welsh Government (2014) *Design Guidance Active Travel (Wales) Act 2013*

228 DfT (2017) *Cycling and Walking Strategy*

229 DfT (2017) 'Cycling'

230 Sustrans (2016) *Response to the consultation on the Draft Cycling and Walking Investment Strategy*

Recommendations:

- **Central and Local Government should increase the proportion of the overall transport budget spent on cycling and walking**, given the significant emissions reduction and net benefits this would realise compared to other forms of transport infrastructure.
- **Government should adopt the 'London Cycling Design Standards' as a national standard.** This would give greater clarity on cycleway safety standards and cut costs across the industry.

'Mobility as a service'

After property, cars are the single largest purchase made by most UK households. Traditionally, car ownership was both aspirational and viewed as a status symbol by many.

However, there is now growing evidence that the nature of car ownership and use is changing. Car ownership continues to increase: the proportion of households in England with access to two or more cars has increased from 26% in 1995/97 to 33% in 2015, whilst the proportion of households with no car has fallen from 30% to 25% over the same period. However, learning to drive is no longer the right of passage that it used to be for young adults. The number of 17-20 year olds passing their test has fallen by 25% since 2007, whilst the proportion of people in their 20s with a full driving licence has fallen from 75% in 1994 to 64% today. Whilst the number of cars on the road continues to grow, the distance travelled per person declined by 10% over the period 2002 to 2012, and the drop in car mileage was particularly pronounced for those in their 20s (-21%) and 30s (-19%).

The market has responded to this by offering various new ways of accessing car use and mobility, which can loosely be grouped under the heading of 'mobility as a service':

- **E-hailing services:** Uber, and other similar companies such as Lyft, Gett, and Hailo, are revolutionising the taxi market by connecting taxi drivers to passengers via mobile app platforms, to provide cars on demand. This enables passengers to buy mobility as a service, and in some cases may allow users to give up their car altogether.
- **Ride Sharing:** BlaBlaCar is a ride-sharing company that connects drivers with spare seats to others who need a lift in the same direction, either for leisure of work purposes. BlaBlaCar now has over 20 million members, operating in 19 countries, and is estimated to have saved their drivers £216 million a year.[231] Uber has launched a similar initiative called UberPool that enables customers to share a ride and split the cost with another person needing a lift in the same direction.[232]
- **Car sharing / car clubs:** These provide access to shared vehicles to members on a pay as you drive basis. There are a variety of models of car clubs, including round-trip, where the vehicle has to be returned to the start point, fixed one-way, where the vehicle can be returned to a different fixed point to pick up, and floating one-way, when there is more flexibility as to the location where the vehicle can be returned. It is estimated that there are 245,000 car club members across Britain, including 193,500 in London alone.[233]

231 https://www.blablacar.co.uk/

232 https://www.uber.com/en-GB/ride/uberpool/

233 Carplus (2017) *Car clubs: improving air quality in London*

- **Fractal Ownership:** This is the newest development in the market. Car manufacturers such as Ford[234], Audi[235] and Nissan[236] are starting to offer fractal ownership of a car whereby ownership of one vehicle is spilt amongst several people.

There are a wide range of benefits from shifting towards the provision of mobility as a service:

- Ride sharing is effectively a demand management measure and has the potential to reduce overall car mileage by increasing vehicle occupancy.
- There is evidence that joining a car club is associated with a reduction in annual car mileage. The annual survey of car clubs 2015/16 in London found that on average people reduced their total household car mileage by 730 miles per year.[237]
- All of the above models have the effect of increasing the utilisation of vehicles (e.g. the proportion of time they are on the road), which means that fewer vehicles are required overall to deliver the same amount of mobility. This reduces the need for parking, freeing up road space.
- The higher utilisation of vehicles means that it is more cost effective to move to ultra-low emission vehicles (which tend to have higher up-front costs but lower fuel costs than conventional vehicles). For example, 18% of the car club fleet in London is electric or hybrid electric[238] (compared to around 1% of the overall car fleet in Britain), and the average car club car produces 29% less CO_2 than the national average car.
- All of the above models give people access to the benefits of using a car without the associated up-front costs, and thus opens car usage to households on lower incomes. 29% of car club members in England and Wales did not have access to a car prior to joining the scheme.[239]
- The combination of these factors means that Mobility as a Service solutions can significantly reduce transport emissions. For example, it is estimated that car club membership reduces a Londoner's transport carbon footprint by 73%.

Overall, the potential for these new technologies and forms of mobility is huge. However, a number of policy and regulatory changes are required to encourage their adoption rather than holding them back (refer to Policy Exchange reports *Up in the Air*[240], and *On the Move*[241]):

- **Car clubs need to be integrated into the transport planning system to enable passengers to make smart transport choices about how they travel. A national set of best practice guidance for car clubs should be agreed.** This could cover a range of issues including appropriate provision of car club parking bays, clearer signage, proactive promotion and support, and planning guidelines for local authorities.
- **Car clubs should be included in public transport charging and information systems.** In theory, it should be possible to integrate car sharing into existing smart public transport systems such as the Oyster system in London. However, aside from a few isolated examples in cities such as Leeds, Nottingham, and Norwich, limited progress has been made on implementing this idea. At a

234 Businesswire (2016) 'Consumers Can Now Share a Vehicle in New Ford Credit Link Pilot Leasing Program'

235 Insider Car News (2014) 'Audi Testing Out Car Sharing Ownership Program'

236 New Era (2016) 'Nissan announce world's first shared car ownership scheme'

237 Carplus (2016) 'Carplus annual survey of car clubs 2015/16'

238 Carplus (2017) *Car clubs: improving air quality in London*

239 Carplus (2016) 'Carplus annual survey of car clubs 2015/16'

240 Howard, R. (2016) *Up in the Air: How to solve London's air quality crisis – Part 2*, Policy Exchange

241 Hind, D. (2015) *On the Move: How to create a more mobile workforce*, Policy Exchange

more basic level, users should be able to access information on car sharing in the same way they do with bus or rail, but again progress has been slow. For example, apps such as CityMapper currently include information on bus, rail, tube and even Uber, but exclude information on car sharing or ride sharing. Part of the reason for this is that there is no consolidated data feed for information on car sharing locations. DfT has already provided some funding for this type of approach under its Developing Car Clubs in England programme, which ran from 2014-16. Further investment by central and/or Local Government is required to maximise this opportunity.

- **Coordinate 'mobility as a service' solutions across city-regions.** One of the factors that has held back the growth in car club membership in London is the fact that policy approaches vary considerably between boroughs. Metro Mayors and Strategic Transport Authorities can play a coordinating role in bringing together boroughs to develop mobility as a service solutions – building on the example of the Car Club Strategy for London led by TfL.[242]
- **Car clubs must be granted access to battery electric vehicle charging networks on a fair an equal basis.** One of the main charging networks in London, Bluepoint London, is also a car sharing company. This creates the possibility of anti-competitive practices – since BluePoint has the ability to set charges and issue access cards to all users, including other car sharing companies offering BEVs. Charging networks need to be brought within the remit of the energy regulator Ofgem, as recommended in the previous section on ULEVs.
- **The Government should explore the possibility of introducing tax benefits that incentivise car-sharing and ride-sharing for trips to work.** The Government should also examine the case for allowing employers to give employees travel vouchers or credits for ride-sharing services through a salary sacrifice scheme.

Connected and autonomous vehicles (CAVs)

Whilst previously regarded as pure 'science fiction', driverless cars are quickly becoming a reality. The common perception of a driverless vehicle is one that is both connected and fully autonomous, but in fact there are many different levels of automation and connectivity possible.

The SAE International Standard J3016 sets out the taxonomy of different levels of vehicle autonomy, as follows:[243]

- SAE Level 0: Human driver does everything.
- SAE Level 1: An automated system on the vehicle can sometimes assist the human driver conduct some parts of the driving task.
- At SAE Level 2: An automated system on the vehicle can actually conduct some parts of the driving task, while the human continues to monitor the driving environment and performs the rest of the driving task.
- At SAE Level 3: An automated system can both actually conduct some parts of the driving task and monitor the driving environment in some instances, but the human driver must be ready to take back control when the automated system requests.
- At SAE Level 4: An automated system can conduct the driving task and monitor the driving environment, and the human need not take back control, but the

242 TfL (2015) *A Car Club Strategy for London: Growing car clubs to support London's transport future*

243 NHTSA (2016) *Federal Automated Vehicles Policy*

automated system can operate only in certain environments and under certain conditions.

- At SAE Level 5: The automated system can perform all driving tasks, under all conditions that a human driver could perform them.

Certain autonomous features, up to SAE Level 3, have been included in road vehicles for many years now, including cruise control, self-parking, and automatic emergency braking. These have somewhat improved vehicle efficiency and safety, but have in no way revolutionised driving. The development of fully autonomous self-driving vehicles to SAE Level 5 has a much greater potential to completely change the transport system.

Vehicle connectivity refers to the ability of the vehicle to recognise and communicate with other agents and the system which it operates within. Vehicle connectivity already includes a number of 'use cases' including navigation, entertainment, remote diagnostics, and tele-matics (the ability to track how well people drive). Further developments in vehicle connectivity are likely to go hand in hand with developments in autonomous vehicles. Autonomous, unconnected vehicles could move around relying only on their own sensors, radar, and cameras, with no external input, but the benefits of automation can be increased with the addition of vehicle connectivity. For example, at a system level, traffic flow will be much more efficient if every vehicle in the system knows where every other vehicle is, and where it is going. This vehicle-to-infrastructure technology would enable congestion to be managed automatically by individual vehicles operating independently. This can be studied in computer simulations known as agent-based simulations to estimate the environmental impact of autonomous vehicles under different scenarios.[244]

Connected and autonomous vehicles have the potential to increase the efficiency of the transport system, improve safety, and reduce congestion, carbon emissions and air pollution. These gains would come about through a variety of means, including:

- **Less aggressive driving:** Motorists can already improve their fuel efficiency by being less aggressive with the brakes and accelerator. Automated vehicles would tune this process for optimum efficiency.
- **Platooning:** This is the idea that vehicles can form 'platoons' on motorways in order to reduce aerodynamic drag and improve their efficiency. Many vehicles already have cruise control in which vehicles can match the speed of other vehicles ahead. Automation and connectivity could improve this process and allow vehicles to follow one another more closely to take advantage of the slipstream from other vehicles.
- **Lower vehicle ownership:** Connected and autonomous vehicles can be combined with the 'mobility as a service' solutions described in the previous section. For example, in 2016 Uber launched a driverless car service in Pittsburgh, Pennsylvania, in which users could hail a driverless vehicle through the Uber app. In theory, this could amplify the gains possible through car sharing alone, by achieving high utilisation of autonomous low emission vehicles.

244 Fagnant, D.J. and Kockelman, K.M. (2014) 'The travel and environmental implications of shared autonomous vehicles, using agent-based model scenarios', *Transportation Research Part C: Emerging Technologies*, Volume 40, Pages 1–13

However, there is a possibility of a 'rebound effect' undermining these benefits. By making road travel more convenient, connected and autonomous vehicles could create an incentive for people to shift from public transport back into cars. This could increase the total number of vehicle miles, which not only increases energy usage and emissions, but also congestion and demand for road space. Autonomous vehicles may also be used by those unable to drive – the young, the elderly and the disabled – which whilst a life-changing technology for many, would also put more people on the road. From both an energy efficiency and transport system point of view, increasing car miles and shifting people from public transport to cars would effectively work against the other modal shift opportunities highlighted above.

Significant investment is now being made into connected and autonomous vehicles, not only by vehicle manufacturers, but also technology companies such as Google and Uber. Whilst significant progress is being made, it appears that this technology is not quite ready and there are also many public acceptance issues. Following the crash of a driverless car in Arizona, Uber recently suspended its driverless car program. This is not an isolated incident: a driver of a Tesla car operating in autopilot mode was killed in 2016, and a Google self-driving car crashed into a bus in the US in 2016. However, many car manufacturers have said that they are looking to offer driverless cars from around 2020.[245]

In terms of **consumer cost**, fully autonomous vehicles are likely to remain considerably more expensive than conventional vehicles for some time to come. However, manufacturers are likely to continue to bring in semi-autonomous features in an incremental fashion – continuing the trend to date. Although autonomous vehicles are likely to be more expensive, the increases in efficiency described above will reduce fuel consumption.

The move towards connected autonomous vehicles is likely to require significant investment in **infrastructure**, although the extent of this investment will remain somewhat uncertain as the technology continues to develop. In the near term, self-driving car developers in America have called for infrastructure upgrades to enable autonomous vehicles to function.[246] Simple things, like visible road markings, make autonomous navigation much easier. In the longer term, manufacturers are developing technologies like real-time 3D mapping to overcome deficiencies in the transport infrastructure. Ideally though, the vehicles should be connected and autonomous, as this will enable autonomous vehicles to navigate complicated transport systems more easily. Rolling out vehicle connectivity could present a challenge for the system in terms of the bandwidth required for the transmission of information. It is estimated that today's connected vehicles already produce 25 Gigabytes of data per hour[247], whilst a fully autonomous connected vehicle could produce 4,000 Gigabytes of data per hour.[248] Connected vehicles interacting with each other and the transport infrastructure will require continuous, high speed, low latency data transfer. With vehicle-to-infrastructure communication, seemingly simple problems like losing data connectivity in a tunnel or built up area could present problems for self-driving cars.

245 http://www.driverless-future.com/?page_id=384

246 The Daily Dot (2014) 'America's failing infrastructure is a serious problem for autonomous vehicles'

247 Hitachi Data Systems (2015) The Internet on Wheels and Hitachi, Ltd

248 Network World (2016) 'Just one autonomous car will use 4,000 GB of data/day'

Recommendations:

- **Government needs to provide clear leadership on the development of connected and autonomous vehicles, with a more coherent joined-up strategy.**
- **Government should conduct further research into the consumer acceptance of connected and autonomous vehicles, and the likely benefit in terms of emission savings.** Manufacturers and technology developers have made a number of claims about the potential benefits from connected and autonomous vehicles. These need to be tested rigorously.
- **DfT needs to work with Highways England, Local Transport Authorities, communication network providers, and the auto industry, to better understand the communication network requirements associated with connected autonomous vehicles, and to future proof investment in the transport system.**
- **Government needs to develop a set of standards and regulations concerning the safety, security and data privacy aspects of connected and autonomous vehicles, drawing on best practice from around the world.**

Conclusions

There are significant opportunities to clean up road transport through modal shift and the adoption of 'mobility as a service' concepts. Progress on many of these opportunities could be made relatively quickly, but this will require far greater focus and coordination by central and local government. Fully autonomous and connected vehicles are still some years away from wide-scale deployment. In order to enable their development the Government has to take certain important steps now, especially with regard to legislation relating to vehicle licencing and insurance, security from cyber-attacks and data privacy. Further investment in communications systems is likely to be required in the future to cater for greater vehicle connectivity.

3

Conclusions and Policy Recommendations

This Chapter of the report provides a set of high level recommendations on how the Government can deliver on the challenge of cleaning up road transport.

As discussed in Chapter 1, road transport plays an essential role in society – moving goods and people around the country. Yet the continued growth in road use means that greenhouse gas emissions from road use have actually increased since 1990 – contrary to the UK's carbon targets. Moreover, road use is a major contributor to air pollution, particularly in urban areas. Official data shows that London, plus 74 other cities and local authorities across the UK still exceed the legal and healthy limit for nitrogen dioxide concentrations.

Need for a new strategy to clean up road transport

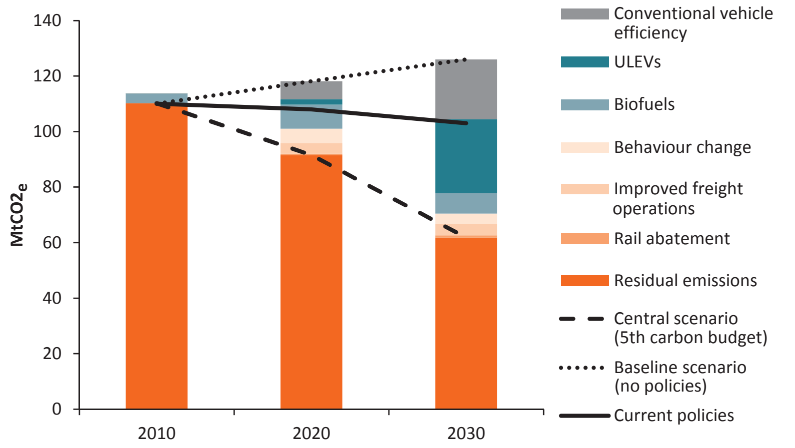
Whilst Government clearly recognises these challenges, the current approach to tackling them is disjointed and insufficient. As it stands, there are a number of strategies and policies in place, but no overarching Government strategy to deliver the required reductions in greenhouse gas emissions, and a weak strategy to address NO_2 pollution.

The Fifth Carbon Budget by the Committee on Climate Change[249] contains the most comprehensive analysis on how to decarbonise surface transport in the UK. Although it is not an official government 'strategy', since the CCC is an advisory body, it is currently the closest thing the UK has to a strategy to decarbonise road transport. The Carbon Budget, and associated 'sectoral strategy' is intended to be a blueprint rather than a firm set of policies. It sets an overall trajectory towards the target of reducing greenhouse gas emissions by 80% from 1990 levels (as per the Climate Change Act 2008). Within this it sets out a trajectory for each individual sector of the economy, such as surface transport, and shows how emission reductions could be made.

The CCC's plan to achieve the 5th Carbon Budget is certainly ambitious. It shows that under a baseline scenario, with no intervention, greenhouse emissions from surface transport are expected to increase by 10% between 2010 and 2030, reaching 126 $MtCO^2e$. By contrast, a scenario consistent with the fifth carbon budget will need to see emissions from surface transport reducing to 62 $MtCO_2e$ (see Figure 3.1). In line with our own analysis in Chapter 2, the CCC's analysis suggests that emission reductions will principally be achieved through the adoption of Ultra Low Emission Vehicles (a saving of 27 $MtCO_2e$ in 2030), and further improvements in conventional vehicles (22 $MtCO_2e$).

249 CCC (2015) *Fifth Carbon Budget*

Figure 3.1: Surface transport abatement in the Fifth Carbon Budget central scenario[250]



However, whilst the CCC's analysis shows that these emission reductions are possible, it also shows that they are unlikely to be delivered by current and planned policies. The CCC suggests that under current and planned policies, emissions from surface transport would only fall to 103 $MtCO_2e$ by 2030 (not the 62 $MtCO_2e$ required to deliver the fifth carbon budget). This means that additional policies will be needed, above and beyond those in place. The CCC provides some high level suggestions on how to achieve a more rapid reduction in surface transport emissions - such as setting emissions targets for new cars and vans to 2030, and tackling barriers to the uptake of ULEVs – but these proposals are yet to be implemented.

Aside from this, Government has developed a number of other strategies and policies aimed at reducing carbon emissions and/or air pollution:

A Strategy for Low Emissions Vehicles in the UK	**Office for Low Emission Vehicles (OLEV), 2013**	Sets out a vision that 'by 2050 almost every car and van in the UK will be an ultra-low emission vehicle, with the UK at the forefront of their design, development and manufacture, making us one of the most attractive locations for ULEV-related inward investment in the world.'
Freight Carbon Review	**DfT (2017)**	The Freight Carbon Review identifies the range of options available to reduce carbon emissions from road freight and proposes the most appropriate mitigation measures for the Government to take forward. Potential measures include efficient driving techniques, improved vehicle design, reducing road miles, alternative fuels like natural gas or biofuel, and switching to hydrogen or battery power.
Future Potential for Modal Shift in the UK Rail Freight Market	**Commissioned by DfT**	The demand for rail freight in the UK is falling, primarily driven by the phasing out coal power stations, which presents an opportunity to shift a proportion of road freight to rail in order to reduce transport emissions. This report outlines the new opportunities for rail freight, as well as potential barriers.

250 Ibid.

Cycling and Walking Investment Strategy	**DfT (2017)**	This is primarily focussed on promoting cycle and walking as a means to improve public health and reduce obesity, but also mentions NO_x emissions reductions as an additional benefit.
Improving Air Quality in the UK	**Defra (2017)**	The UK Government is legally obliged to reduce levels of nitrogen dioxide to below EU limits. This draft plan proposes a range of potential solutions including the implementation of Clean Air Zones in the most polluted cities, incentives for alternative-fuelled vehicles and ULEVs, more detailed and accurate environmental performance information on vehicles, and updating Government procurement guidelines to encourage the purchase of cleaner vehicles.

It is unclear whether these strategies add up to the carbon emission trajectory as set out in the fifth carbon budget, but it is unlikely given the significant gap between this and the CCC's 'current policies' scenario (see Figure 3.1). Whilst several of the above strategies and policies have been developed since the fifth carbon budget report, they are largely incremental in nature, and unlikely to deliver the required step-change in emissions.

Overall, it is clear that Government needs to develop a new strategy to clean up road transport in order to deliver the emissions reductions required under the fifth carbon budget, and to successfully address air pollution. This could be developed as a standalone strategy, or as part of the Emissions Reduction Plan (or 'Clean Growth Plan') which the Government is due to release later this year.

Based on analysis in this and previous Policy Exchange reports, we suggest that the approach to cleaning up road transport should follow the following broad principles:

1. Make a clear commitment to clean up road transport

Analysis by ourselves and others suggests that reducing transport emissions will be challenging and costly. Carbon emissions from road transport have increased since 1990 despite efforts to reduce them. Government needs to set a clear direction for travel, with much clearer objectives about what should be achieved by when. **The new strategy should reiterate the carbon targets set out in the fifth carbon budget, and set out a credible plan of action to deliver them.** In line with the Conservative Manifesto, the Government should focus on outcome-based targets, such as reducing total greenhouse gas emissions from road transport – rather than setting targets for any particular technology, or to incorporate a certain amount of renewable transport fuel.

There needs to be closer integration between policies to reduce greenhouse gas emissions and policies to clean up air pollution. The policy to promote diesel vehicles from the 1990s onwards has undermined efforts to improve air quality. There are several other examples where policies to reduce carbon emissions have had a detrimental impact on air quality, as noted in our report, *Up in the Air*. The Government needs to learn from these mistakes, and ensure that policies concerning greenhouse gas emissions and air quality are more closely aligned. For example, whilst the CCC's Fifth Carbon Budget recognises that measures to reduce greenhouse gas emissions may also reduce air pollution, it explicitly does not factor these benefits into its cost-benefit analyses. On this basis, the analysis will tend to underestimate the overall benefits from measures such as the adoption of ULEVs, or switching to alternative fuels. Government needs to do more to recognise the synergies and tensions between these two areas of policy.

2. Provide leadership across Government

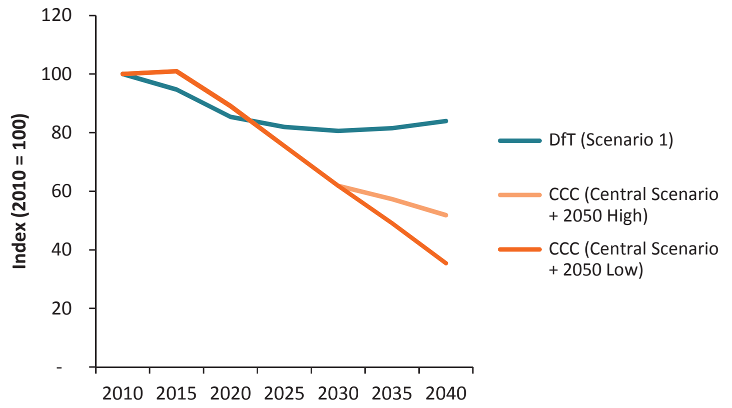
One of the striking features of the current approach is that so many different parts of Government are involved. The strategies and policies identified above have been produced by four different organisations – the CCC, DfT, Defra, and OLEV (which itself is a joint unit between the DfT and BEIS). Beyond this, HM Treasury has an interest in transport related taxes, whilst DCLG, the Devolved Administrations, Local Authorities and LEPs have an interest in local transport planning and air pollution. Ofgem has a role in the regulation of energy markets and monopoly networks. The National Infrastructure Commission is tasked with assessing infrastructure needs, in order to support sustainable economic growth and improve quality of life – with a plan to produce the first National Infrastructure Assessment in 2018. In other words, **the governance of road transport emissions is highly complex, and it is unclear where the overall authority and leadership lies.** There is a risk that silos operating in different parts of Government fail to align around the optimal solutions.

A clear indication of this lack of joined up thinking is that different parts of Government appear to be planning for radically different futures for road transport emissions. As part of this study we reviewed the transport emission projections produced by the Committee on Climate Change against those produced by the Department for Transport (which are used for transport planning purposes).[251] The CCC's Central scenario is for road transport emissions to fall by 11% by 2020, 38% by 2030, and 48-65% by 2040 (relative to 2010).[252] By contrast, the DfT's projections show total road transport emissions falling by only 19% by 2030, and then *increasing* between 2030 and 2040. This is likely due to the fact that the DfT forecasts significant growth in vehicle miles (+42% between 2010 and 2040), and makes relatively conservative assumptions on vehicle efficiency and the uptake of ultra-low emission vehicles. **Greater coordination is needed to ensure that all parts of Government are working towards a common vision of the future of road transport. At present we have a Department for Transport that is not planning on the basis of hitting the CCC's suggested path for vehicle emissions.**

251 This analysis compares the CCC's Fifth Carbon Budget Sectoral Scenarios, with the DfT's Road Traffic Forecasts. It should be noted that the former figures are for the UK, whilst the latter are for England and Wales only.

252 The 2035 and 2040 figures for the CCC are a straight line extrapolation of figures for 2030 and 2040.

Figure 3.2: Road transport emissions scenarios



Under the Cameron administration, the task of providing leadership and joining up departments on these issues fell to the Inter-Ministerial 'Clean Growth' Group. It is unclear whether this group still exists. **We recommend that the Government upgrades this to a Cabinet-level committee focused on emissions reduction and clean growth – potentially as a sub-committee to the Economy and Industrial Strategy Committee.**

Whilst greater top-down leadership and coordination is needed, it goes without saying that local delivery will also be crucially important, with action at a variety of levels (city/region, and individual local authorities) tailored to specific circumstances. London has led the rest of the UK in many respects – bringing in congestion charging, low emission zones, franchising and licensing arrangements to encourage lower emission buses and taxis, electric charging infrastructure and car clubs. This is in large part due to the fact that London is starting from a substantially worse position in terms of emissions and congestion. **This strategic approach and urban leadership needs to be rolled out more widely – in particular by the new Metro Mayors and bodies such as Midlands Connect, Transport for the North, and Local Enterprise Partnerships.**

3. Put the consumer first

In our previous report, *The Customer is Always Right*[253] we argued that under the Coalition Government and previous Labour administrations, energy policy became increasingly detached from what consumers and voters want. The report argued that voters identify the cost of living as their number one policy issue, and energy bills as the number one concern in terms of household budgets – but despite this, successive Government policies contributed to a significant increase in energy costs.

The Government needs to ensure that consumers remain at the heart of the new strategy to clean up road transport. As noted in the previous Chapter, vehicles are amongst the largest purchases that most households make (after

253 Howard, R. (2015) *The Customer is Always Right*, Policy Exchange.

housing). The average household spends 13.8% of their total household budget on transport, 10.5% of which relates to personal vehicles (as opposed to public transport).[254] Therefore, any changes to policies, regulations, taxes and subsidies concerning vehicles could potentially have a significant impact on household budgets and the cost of living.

The Government must ensure that policies to clean up air pollution do not unduly penalise motorists – a point we stressed in our previous report, *Up in the Air*. For example, it would be morally unacceptable for the Government to heavily penalise diesel drivers, who bought their vehicles in good faith and were actively encouraged to do so by successive Governments through a number of financial incentives geared towards lower CO_2 vehicles. Government should adopt a 'carrot and stick' approach to cleaning up road transport, with a mix of penalties for the most polluting vehicles and incentives for cleaner vehicles. To this end, Policy Exchange recommends putting in place a diesel scrappage scheme as an incentive to take more polluting vehicles off the road, alongside measures such as Clean Air Zones that will restrict older diesel vehicles from entering cities.

4. Pursue a technology-neutral, least-cost approach

- As noted above, energy costs are a key concern for households and voters. For this reason, **the Government must focus on the lowest cost solutions to clean up road transport, in order to minimise the burden on consumers and taxpayers.** This is best achieved by adopting a technology-neutral approach – pursuing the lowest cost technologies to achieve a given environmental outcome rather than pursuing particular technologies. As highlighted in the previous Chapter, there are a range of technology options including: further improvements in conventional vehicles, ultra-low emission vehicles (electric and hydrogen), alternative fuels (biofuels and gaseous fuels), modal shift (to rail, buses and cycling), and behavioural change through the adoption of new technologies such as car sharing and connected, autonomous vehicles. Our analysis suggests that there is no 'single bullet' but that a range of options will be required to clean up road transport across different vehicle types and time-scales.
- The Office for Low Emission Vehicles has stated that it is pursuing a technology neutral approach. However, whilst it is true that OLEV considers the range of ultra-low emission vehicles available (electric, plug in hybrid, hydrogen) OLEV's remit is by definition limited to ultra-low emission vehicles. As such, OLEV does not consider alternative technologies to mitigate carbon emissions or air pollution – such as conventional vehicle efficiency, alternative fuels, or modal shift.
- The Government should avoid setting technology specific targets, as these tend to bind the hand of Government, increase costs, and constrain thinking. For example, **we propose that following Brexit, the Government should scrap European Renewable Energy Targets, including the target to source 10% of transport fuel from renewables by 2020.** As discussed above, this would be a costly target to achieve. Moreover, in pursuing a technology specific target such as the renewables target, policymakers often overlook other more cost-effective ways to reduce emissions, such as improving vehicle efficiency. **Equally,**

254 Source: ONS, Household Expenditure Survey

the Government should avoid setting targets for the uptake of ultra-low emission vehicles (as proposed by an Environmental Audit Committee report in 2016).[255] The uptake of ULEVs should be determined by market forces, not by Government decree. The Government should concern itself with outcome based measures (in this case greenhouse gas emissions and pollution levels) rather than technology-specific targets.

- **The Government's approach to cleaning up road transport should combine short term 'quick wins' with a long term vision.** Our analysis in the previous Chapter suggested that there are several short term opportunities to reduce transport emissions – such as making further improvements in conventional vehicles, scrapping or retrofitting older diesel vehicles, switching to alternative fuels such as LPG or CNG for heavy duty vehicles, and restricting the most polluting vehicles from entering cities. In the medium term (during the 2020s), further progress is likely to be made by increasing the uptake of ultra-low emission cars and light vans. Longer term opportunities include the adoption of ultra-low emission technologies within heavy duty vehicles and fully autonomous vehicles.

5. Tackle system challenges

The analysis presented in Chapter 2 underlines the fact that cleaning up road transport will have significant implications for infrastructure – including transport, energy and even communications systems. Many of the options considered will require significant investment either to build new networks (e.g. in the case of hydrogen) or upgrade existing ones (e.g. battery electric vehicles). For example, our analysis suggests that battery electric cars could become cost competitive without subsidies in the early 2020s. This could result in an inflection point in the take-up of these vehicles, leading to a surge in sales. Sufficient charging infrastructure will need to be in place ahead of demand to facilitate this roll-out, and smart charging technologies will be needed to manage the new demands on the power system. If vehicles require additional connectivity, then this could also have significant implications for communications networks.

Whilst we can already identify and describe these system implications at high level, there is still significant uncertainty as to the precise nature, scale and timing of the impacts that new vehicle technologies will have on transport, energy and communications systems. This raises questions in terms of how to plan network and system investments given the level of uncertainty.

For example, existing energy networks (electricity and gas) are regulated by Ofgem under the RIIO system of price controls, with the current set of 8-year price controls ending in 2021/2023. These price controls define the overall envelope of charges that network companies can pass on to their customers. The RIIO model can cater for a certain amount of uncertainty – for example by converting certain risk parameters into incentive mechanisms (i.e. network company revenues increase if they connect more customers, or decrease if they connect fewer customers). However, there is a limit to the ability of the current regulatory model to cope with periods of significant change and uncertainty. Given the level of uncertainty about how and when road transport will be decarbonised, it is hard to see how the network companies or the regulator will be able to accurately predict the level or

255 HoC (2017) *Sustainability in the Department for Transport*

type of investment required in networks. For example, Ofgem will shortly begin planning the next round of RIIO price controls, which will run to 2029/31. It is very difficult to say now with any precision what road use patterns are likely to be in 2030, let alone to identify the precise implications for energy networks. **For this reason, we suggest that Ofgem should seriously consider shortening the length of the next set of price controls (e.g. from 8 to 5 years) or building in more significant re-openers to cater for uncertainties.**

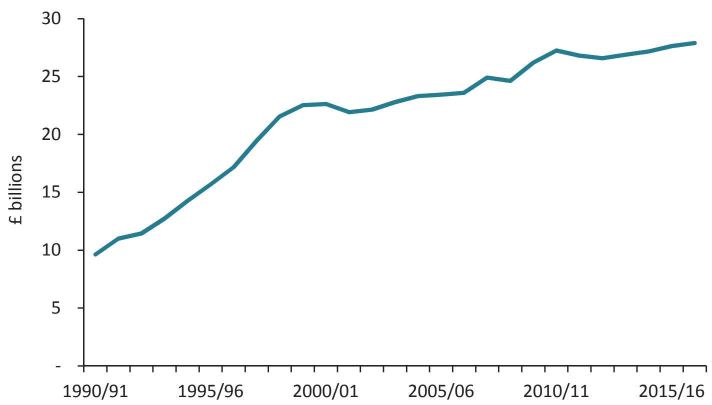
Ofgem also needs to do more to ensure that network price controls reflect the transition taking place within different parts of the energy system. This report demonstrates that the decarbonisation of road transport could have significant network implications, but so too could the decarbonisation of heating (as discussed in our previous report, *Too Hot to Handle?*). For example, both heating and transport could move towards greater electrification and/or the use of hydrogen in the future. Ofgem and the network companies must be alive to the transitions taking place within these systems and the synergies and tensions that may arise.

Fiscal implications of cleaning up road transport

Whilst the decarbonisation of road transport is clearly desirable from an environmental point of view, it could present a major fiscal challenge for the Government. At present the Government raises nearly £34 billion per year through taxes on road use – the main taxes being fuel duty, and VED or 'road tax'. This far outweighs the cost of maintaining and upgrading the road network (£9.4 billion in 2015/16)[256] which means that road use makes a significant net contribution to public finances.

Fuel duty has become a major source of Government revenue in recent years. In 2016/17 alone it brought in £27.9 billion of tax receipts (representing 4% of total Government receipts) up from less than £10 billion in 1990 (Figure 3.3). The total amount raised through fuel duty is roughly equivalent to the receipts from business rates (£27.8 billion) or council tax (£28.8 billion). In addition to this, VED brings in a further £5.8 billion.

Figure 3.3: Total Fuel Duty receipts (£, nominal)



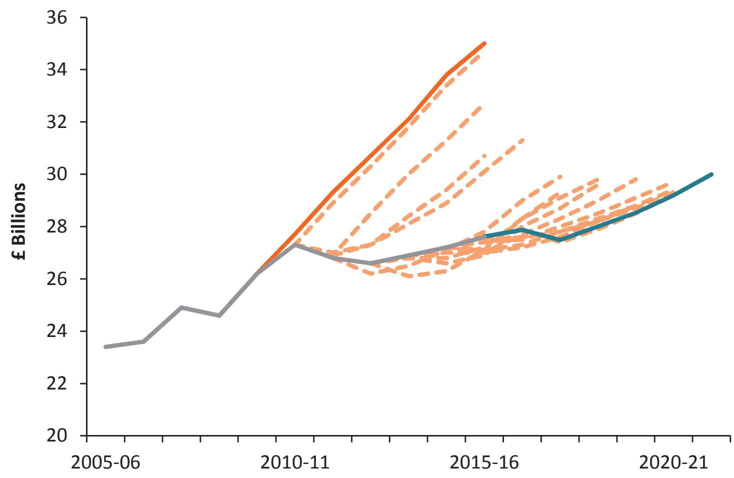
256 HM Treasury (2016) *Public Sector Statistical analysis 2016*

However, there are two factors which could gradually erode this position:

Firstly, one of the recurring themes in recent budgets has been the Government's decision to cancel the fuel duty escalator – effectively freezing fuel duty in nominal terms (and thereby reducing it in real terms). Every year since 2010, the Chancellor has been able to chalk this up as a significant win for motorists, for example in Budget 2016 it was reported that the freeze in fuel duty since 2010 saves the average motorist £75 per year. This is appealing from a political perspective, insofar as it benefits the 'Just About Managing' households and businesses that Government is trying to help out.

However, from a fiscal forecasting point of view, it is more problematic. Twice a year, the OBR and HM Treasury produce a set of fiscal forecasts based on the current set of agreed policies. Despite the fact that the Government cancels the fuel duty escalator each year, it remains the Government's stated position that fuel duty will rise. This means that the OBR and HM Treasury build this increase into their medium-term forecasts each year, and then have to subsequently change them when the fuel duty increase is cancelled. The following chart shows how the OBR has repeatedly revised down its forecasts for fuel duty receipts, year on year. Total fuel duties in 2015-16 (£27.6 billion) were £7 billion less than the OBR was forecasting for the same year in June 2010 (£34.7 billion).

Figure 3.4: Fuel Duty Forecasts since 2010 (Source: OBR, Economic and Fiscal Outlook, March 2016, November 2016 and March 2017)



This pattern affects not only the fuel duty figures to date, but also the medium term forecasts. Forecasts by HM Treasury and OBR currently show fuel duties rising to £29.2 billion by 2020-21 (an increase of £1.3 billion compared to 2016-17). However, if the Government continues to cancel the fuel duty escalator, then it is entirely possible that the total fuel duty receipts could start to fall. **We estimate that if the fuel duty escalator is cancelled out to 2020-21, then the receipts would be £25.3 billion in 2020/21, not the £29.2 billion assumed by the OBR. This represents nearly a £4 billion per year hole in the public finances.**

Secondly, and of even greater significance, is the impact that the decarbonisation of road transport could have on road tax receipts. Both fuel duty and VED are effectively taxes on carbon emissions. Fuel duty places a direct tax on the use of fossil fuels, whilst road tax rates are in part defined according to CO_2 emissions bands. It goes without saying that as road transport is decarbonised, the total receipts from fuel duty and VED are likely to decrease (all else being equal). As with many 'green' taxes, there comes a point where successive increases in the tax rate no longer yield any additional revenue, since they have the effect of changing behaviour - in this case to reduce the use of fossil fuels and switch to alternatives.

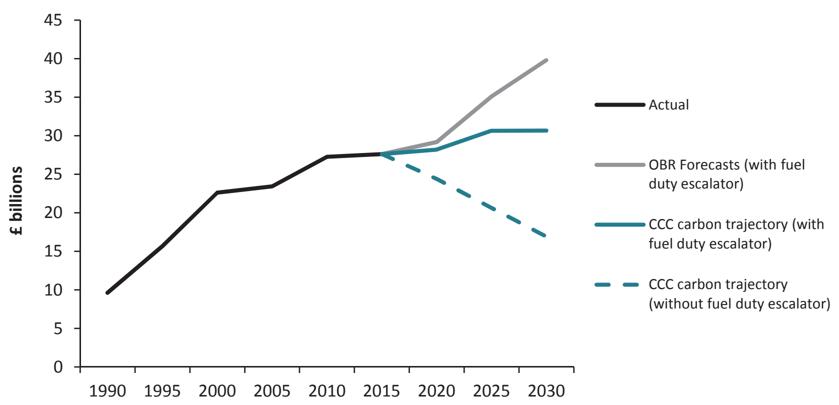
As part of this study, Policy Exchange has constructed a model for forecasting fuel duty receipts according to a range of parameters such as the fuel duty rate charged, total road usage, and total road transport emissions – mimicking the models produced by the OBR. We have constructed two scenarios based on the carbon emission trajectory in the Committee on Climate Change's fifth carbon budget. We estimate that if the fuel duty escalator is applied in full, then total fuel duty receipts would increase to around £31 billion in 2030. If Government continues to cancel the fuel duty escalator then receipts would fall to around £17 billion in 2030 – a reduction of 40% compared to today (in nominal terms).

By contrast, the long term projections in the OBR's Fiscal Sustainability Report[257] suggest that fuel duty receipts could increase to around £40 billion in 2030. Their forecast is based on the DfT's transport and emission projections, which as shown above are inconsistent with the CCC's Fifth Carbon Budget.

Comparing the two sets of scenarios, this shows that if we achieve the fifth carbon budget, then fuel duty receipts could be £9-23 billion lower in 2030 than the OBR assumes in its long-term fiscal forecasts. On a cumulative basis, this represents a loss of £60-170 billion in tax receipts compared to the OBR's long term forecasts between now and 2030.

Our long range forecast shows that if road transport emissions fall in line with the emissions trajectory suggested by the CCC, and the Government continues to cancel the fuel duty escalator, then fuel duty receipts would fall to £10-14 billion by 2040. **In this scenario, the total tax take from road use could be equal to or less than the cost of maintaining the road network by the 2030s.**

Figure 3.5: Scenarios for fuel duty receipts



257 OBR (2014) Fiscal Sustainability Report. More recent versions of the Fiscal Sustainability Report are available, however the 2014 version included a detailed analysis of future fuel duty receipts.

The Government therefore faces a conundrum: it wants to drive the decarbonisation of road transport and the uptake of lower emission vehicles through fiscal incentives, but this will almost certainly erode the tax base.

A significant part of the appeal of ULEVs at present is that they pay very little in the way of tax (and in fact receive significant direct subsidies in the form of the Plug-In Car Grant). The carbon tax levied on electricity is around £20 per tonne (in the form of the Carbon Price Support and EU Emissions Trading Scheme) compared to a carbon tax of around £250 per tonne on petrol and diesel (in the form of fuel duty). In addition to this, VAT is charged at the standard rate of 20% on petrol and diesel, but at a reduced rate of 5% on electricity. At present there is no carbon tax or fuel duty placed on hydrogen, although it is subject to the standard rate of VAT. ULEVs receive further tax breaks in the form of reduced road tax, reduced company car tax, enhanced capital allowances, and a range of other incentives (see Box 3, Chapter 2). Overall, ULEVs receive a very favourable tax treatment at present, plus direct subsidies in the form of grants. There is a clear tension between the Government's desire to shift to ULEVs from a carbon and air pollution point of view, versus the impact this will have on public finances in the long term.

HM Treasury has recognised this to an extent and has already made changes to VED rates to stem the loss of tax receipts. VED reforms were announced in the 2015 Budget and came into effect in April 2017. VED has moved from a system with many different CO_2 emission bands, to a simplified, three-tiered approach. From 1 April 2017, new vehicles will only be exempt from VED if they have zero tailpipe emissions, and most other vehicles will pay a flat 'Standard Rate' of £140 annually (with a premium of £310, for five years, on cars worth over £40,000). This reform aimed to 'make [VED] fairer for motorists and reflect improvements in new car CO_2 emissions'.[258] Changes have also been made to the Company Car Tax regime, reducing the tax advantage of choosing a lower emission vehicle.

The changes to VED and Company Car Tax rates are indicative of further changes that may be necessary down the line. As road transport is decarbonised, it will become increasingly difficult to tax fossil fuels as a proxy for road use, as more and more vehicles will be low carbon or zero carbon. The implication of this is that in order to shore up road taxes, the Government may need to tax road use directly, rather than taxing road use indirectly through fuel duties. The changes to VED are a first step towards this: most road users will pay the same flat fee going forward. However, in time the Government will need to seriously consider whether it is necessary to move to a system of road user charging – either on selected roads (e.g. road tolls), in certain cities (e.g. congestion charging zones), or across the entire network (e.g. using GPS systems).

This question of how roads will be paid for in the future is the subject of the 2017 Wolfson prize for Economics, which Policy Exchange is coordinating. Entrants have been invited to answer the question: *'how can we pay for better, safer, more reliable roads in a way that is fair to road users and good for the economy and the environment?'* Central to this question is the decarbonisation of road transport, and what this means in terms of road use and road taxation. The competition finalists will be announced in July 2017.

258 www.parliament.uk (2016) 'Heat and transport: beyond 2020'

Road transport plays a crucial role in society – enabling people and goods to move around the country, and thereby sustaining economic growth. However, road transport also gives rise to significant negative externalities: it is the principal cause of urban air pollution, and a major contributor to UK greenhouse gas emissions.

This report provides a picture of recent trends in road use, and a review of the main technological options to address road transport emissions - from new technologies like electric, hydrogen and natural gas vehicles, to making conventional vehicles more efficient, and encouraging people to take public transport.

The report argues that the Government needs to take more coordinated and assertive action to address the twin problems of carbon emissions and air pollution from road use. It identifies that the decarbonisation of road transport could lead to fiscal challenges in the future, as the shift to lower carbon vehicles erodes fuel duty receipts. The move to lower emission vehicles will also require significant investment in energy, transport and communications infrastructure.

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